Document made available under the Patent Cooperation Treaty (PCT)

International application number: PCT/IL05/000152

International filing date: 07 February 2005 (07.02.2005)

Document type: Certified copy of priority document

Document details: Country/Office: US
Number: 60/542,680
Filing date: 09 February 2004 (09.02.2004)

Date of receipt at the International Bureau: 15 June 2005 (15.06.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)

PCT/IL 2005 / 000152 1.6
01 JUN 2005

S3331

PA 1324227

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE

United States Patent and Trademark Office

May 23, 2005

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THE UNITED STATES PATENT AND TRADEMARK OFFICE OF THOSE PAPERS OF THE BELOW IDENTIFIED PATENT APPLICATION THAT MET THE REQUIREMENTS TO BE GRANTED A FILING DATE UNDER 35 USC 111.

APPLICATION NUMBER: ***60/542,680***
FILING DATE: ***February 09, 2004***

By Authority of the
COMMISSIONER OF PATENTS AND TRADEMARKS

N. Williams

N. WILLIAMS
Certifying Officer

16558 U.S. PTO

PTO/SB/16 (10-01)
Approved for use through10/31/2002. OMB 0651-0032
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

17302 U.S. PTO 60/542680 020904

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Expr ss Mail Lab l N .

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Gad	Terliuc	Raanana, Israel

☐ *Additional inventors are being named on the* ___ *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

Improved micro-robot and accessories for endoscopy and in-pipe locomotion

CORRESPONDENCE ADDRESS

Direct all correspondence to:

☐ Customer Number [ ] *Type Customer Number here* → *Place Customer Number Bar Code Label here*

OR

☑ Firm or Individual Name	Gad Terliuc				
Address	12 Macabi street				
Address					
City	Raanana	State		ZIP	43254
Country	Israel	Telephone	972-9-7441919	Fax	---

ENCLOSED APPLICATION PARTS *(check all that apply)*

☑ Specification *Number of Pages* 16
☑ Drawing(s) *Number of Sheets* 17
☐ Application Data Sheet. See 37 CFR 1.76
☐ CD(s), Number
☐ Other (specify)

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☑ Applicant claims small entity status. See 37 CFR 1.27.
☐ A check or money order is enclosed to cover the filing fees
☐ The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number:
☑ Payment by credit card. Form PTO-2038 is attached.

FILING FEE AMOUNT ($): $80.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.
☑ No.
☐ Yes, the name of the U.S. Government agency and the Government contract number are: ____________

Respectfully submitted,

SIGNATURE ____________

Date 01/26/2004

TYPED or PRINTED NAME Gad Terliuc

REGISTRATION NO. *(if appropriate)*

Docket Number:

TELEPHONE 972- 9-7441919

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

Monday, January 26th, 2004
Title: **Improved micro-robot and accessories for endoscopy and in-pipe locomotion.**
Inventor: Gad Terliuc
This is a provisional application for a US patent.

FIELD OF THE INVENTION

The invention relates to a micro-robot (hereinafter also denoted "MR") for progressing in the interior of a tubular pipe, with self-locomotion capability, and to related accessories. More specifically, it relates to a MR with self-locomotion and related accessories for progressing in the interior of a tubular pipe of varying cross-section and diameter, and of flexible and stretchable walls. Particularly, it relates to a MR with self-locomotion and accessories for inspecting, examining and treating the interior of human or animals' tubular cavities and canals. More particularly, it relates to a MR with self-locomotion and accessories for performing endoscopy or colonoscopy.

INTRODUCTION

As well discussed in the art, conventional endoscopy and colonoscopy suffer from many drawbacks. In a conventional endoscopy, a highly flexible longitudinal device is inserted into the colon, arteries, etc., through a natural or surgical opening. The endoscope is pushed through from its tail, to afford the progress of the endoscope's head, carrying the inspection and treatment tools. Such tools may include an illuminating source (e.g., LED) and fiber-optics bundle or CCD for transmitting an optical image, an ultrasound transducer, or other sensors. Conventional endoscopes comprise a concentric central tube along their longitudinal axis. This tubular opening is used for inserting long and narrow accessories (e.g., snares, needles, probes, tweezers, etc) within the endoscope to the front of the endoscope head, for diagnostic, therapeutic and surgical tasks.

Few of the major deficiencies of traditional endoscopes are:

- Limited steering ability
- Limited passage length in the intestine (or other interior ducts).
- Cannot traverse tight bends in the intestine (or other interior ducts).
- May cause damage to the interior of the intestine while pushed through.
- Their positioning is not "locked" relative to the intestine's walls, which could be beneficial for diagnosis or treatment of a desired point of the intestine (e.g., biopsy, laser cutting, etc).

Thus, a new type of endoscopes is being developed, to overcome such deficiencies of traditional endoscopy. These are longitudinal but short micro-robots (MR), with self-locomotion and self-steering capability, which can advance or retract within the colon

based on their own motorizing means, and supported by the colon's interior walls which are used for counter-force. Some of the prior art discussing endoscopic MR include the following US patents and patent applications:

- US 5,337,732
- US 5,662,587
- US 2002/0029915 A1
- US 2003/0065250 A1
- US 2002/0111535 A1
- US 2002/0156347 A1
- US 2002/0171385 A1
- US 2002/0173700 A1

In general, propagation mechanism of most of the prior art could be divided into two main categories: an inchworm type locomotion, which artificially mimics the propagation principles of a worm; and wheel-based propagation, in which circular wheels or caterpillar chains or so are moved against the colon's walls to generate a relative movement.

While addressing to some extent the steering and mobility issues, the various prior art MR fail to afford some or all of the following features and properties:

- A simple structure with only few components, which could afford the miniaturization, required for passage within the intestine, and mostly the small intestine (and moreover mobility through ducts of smaller diameter, such as arteries).
- A simple propagation method.
- A short length of the MR.
- A design and a gripping mechanism that support propagation through ducts of a large diameter variance. For example, the diameters ratio of the large and small intestine may reach a factor of three. The design of the MR should support gripping of such differing diameters, in order to allow passage through the entire intestine.
- A gripping mechanism (for gripping the internal walls of the intestine) that is substantially pressure limited, rather than diameter limited. That is, the gripping pressure against the intestinal walls can be tuned and set regardless of the diameter of the intestine at the gripping point.
- Gripping through the whole internal perimeter of the intestine, rather than point gripping or line gripping by gripping-legs, wheels, etc.
- A center-free mechanical structure that allows for a concentric, hollow opening through the MR length, for facilitating the insertion of conventional accessories (scissors, cutters, etc., as discussed above) through the MR to the examined area ahead of it, and to facilitate air inflation of the intestine ahead of the endoscope. Current endoscope micro-robots do not afford an empty central cavity, due to their complicated mechanical structure and operation principles (for example, inchworm MR that require extensor modules which vary their length, wheel-based MR that utilize a central motorizing screw to transfer the motion to peripheral wheels, etc). The lack of a longitudinal pipe through the MR is limiting and inconvenient, as all the accessories, inspection and diagnostic tools and the like must be located on the head of the MR. This limits the variety and number of accessories during the

operation, complicates miniaturization, and is different than what gastro-enterologist physicians are used to in conventional endoscopy.

- A flexible, hollow, long tubular tail which is dragged by the MR, extending to the exterior of the body, which is used for leading long accessories as described above to the front of the MR, for air inflation of the intestine, and the like.
- A MR cover for isolating the MR from the intestinal environment and for improving gripping contact, which complies with the structure and movements of mechanical parts of the MR. In particular, such a cover which is disposable (for single-use of few uses).

SUMMARY OF THE INVENTION

It is appreciated that the description of the invention hereinafter will focus on endoscopy of the gastrointestinal system, but the scope of the invention is not limited to this system and some or all of the described methods, concepts, apparatuses, systems, notions and so, may be applicable to endoscopy of other organic ducts. For example, it may be used to navigate within the vascular system, for inspection and treatment. For instance, it could be used to inflate a narrowed vein, as currently done with dedicated balloons.
Moreover, they could be applicable also to other fields in which a MR is to propagate through a tubular duct, and particularly to examine, inspect or treat the internal surface of this duct. Such fields may include the internal inspection and fixing of industrial pipes for chemicals transport, installation pipes, applications where a cable or wire should be transferred through a pipe (electricity, phone or communication cables etc) and hence using the MR as a locomotive carrier, and more.

As will become apparent from the detailed description of few embodiments and the accompanying drawings, a major aspect of the present invention is an improved micro-robot (MR), which is capable of progressing forward or backward (namely advancing or retracting) inside a tube, while generating its own locomotion. In general, it can propagate in a rigid or flexible duct, of a constant or varying diameter and cross-section, having a straight or curved route.

Similarly to other MR or conventional endoscopes, the <u>head</u> (the front part) of this MR may be equipped with functionalities and tools as well known in the art, such as (but not limited to): an illumination source (e.g., LED) and optical signal collection device (e.g., optical fiber bundle, CCD, micro-camera); fiber optic for transmitting a laser beam (e.g., for cutting, cauterizing or evaporating tissue); mechanical accessories (e.g., micro-tweezers, scissors, needle, tissue-cutter, biopsy arms and storage cell); or any other known sensors and diagnostic, therapeutic and surgical tools.

The MR tail (the rear part of the MR) may be attached to a long, flexible wire or a bundle of wires, extending to the exterior of the body, as needed by the MR operation mechanism and functionalities. Some of the wires or cables within this bundle may be:

- Fiber optic (or few fiber optics), for optical image transmission from the MR, laser beam application or both.
- Electrical wire (or wires), for information transmitting and receiving, electrical power and commands signals transferring, electrical currents for operation of actuators, solenoids or valves of the MR, probing signals transmission and reception, and so.
- A flexible, hollow, long tubular tail, which is used for leading long accessories as described above to the front of the MR, for air inflation of the intestine, for insertion of therapeutic or other fluids to the examined/treated area of the intestine, for supplying operational air pressure or vacuum to the MR, and the like, as needed by the operational mechanism of the MR and by the application
- Any other flexible wire, cable and/or tube as needed and applicable.

This bundle of cables, tubes and wires is dragged by the MR while it advances in the intestine, with its rear edge out of the intestine, connected to the appropriate controls and supplies (e.g., electrical control unit, air pressure/vacuum supply, etc.). It is also appreciated that this bundle could be lubricated (with a bio-compatible lubricant as commonly used in various medical applications) or coated with an anti-friction or non-sticking coating (e.g., Teflon), to afford smooth and frictionless propagation through the intestine. When the MR is retracting in the intestine backward, toward its insertion opening, this bundle of cables is pulled out gently, either manually or mechanically. It is appreciated that a correlation could be made between the propagation distance of the MR (either advancing or retracting) and the dragging or pulling length of the bundle, thus avoiding either over-tension or stepping of the MR on the bundle, respectively. The bundle could also be used to gently pull out the MR from the intestine, in case of a failure that disables the MR propagation ability.

It is noted that the above-mentioned rear cables or tubes for air pressure, accessories insertion or electrical and optical connection, is not a must. In some applications and configurations of the MR, it is optional to skip some or all of them. For example, the flexible tube could be omitted if all of the accessories are mounted on the MR head and none should be inserted separately through the intestine to the examined area. As well, the electrical and/or optical wiring could be omitted if a wireless solution is applied. In such a case, the MR should include its own power source (a small battery), and means to transmit information to and receive instructions from a remote (external) unit, as well known in the art of wireless communication.

The main body of the MR, between the MR head and MR tail as described above, is of a longitudinal but short shape, for example of a cylindrical shape, with diameter substantially smaller than the smallest diameter of the intestine to be passed through. This main body of the MR is responsible for the locomotive propagation of the MR. Two (or more) clamping (namely gripping) units are located at different distances along its length.

More specifically, each of these clamping units is encircling the main body. Each of these clamping units could be either in an "extended" (namely "gripping" or "clamping") state, in which it is pressed against the perimeter of the intestine's internal walls thus gripping it, or in a "contracted" state, in which it is contracted against the main body thus not gripping the intestine but rather affording an external diameter of the MR which is substantially smaller than the diameter of the intestine. In the basic propagation scheme of this MR, one clamping unit, for example the rear clamping unit, is fixed to the main body, while a second clamping unit, in this example the front clamping unit, is movable forward and backward along the main body, through appropriate actuators, cylinders and controls. The propagation of the MR (advancing or retracting) is achieved by an appropriate sequence of extended/contracted states of the clamping units, along with forward/backward movement of the front clamping unit. In the present example, an advancing sequence is accomplished by the following steps in that order:

1. Starting position- rear clamping unit extended, front clamping unit contracted and backward.
2. Front clamping unit is moved forward (to the front side of the main body).
3. Front clamping unit is extended.
4. Rear clamping unit is contracted.
5. Front clamping unit is moved backward. Since it grips the intestine, the result of this step is that the MR is advancing through the intestine.
6. Rear clamping unit is extended.
7. Front clamping unit is contracted. Thus, a step forward is accomplished, and the MR is in the starting position for another step, and so on as needed.

Similarly, a retracting sequence comprises the following steps in that order:

1. Starting position- rear clamping unit extended, front clamping unit contracted and backward.
2. Front clamping unit is extended.
3. Rear clamping unit is contracted.
4. Front clamping unit is moved forward (to the front side of the main body). Since it grips the intestine, the result of this step is that the MR is retracting through the intestine.
5. Rear clamping unit is extended.
6. Front clamping unit is contracted.
7. Front clamping unit is moved backward. Thus, a step forward is accomplished, and the MR is in the starting position for another step, and so on as needed.

The motion of this MR resembles in a sense to the known inchworm-like locomotion, but in contrast to it, in the present invention there is no extensor (namely deformer) unit between the clamping units, that changes its length as part of the propagation sequence, but rather the propagation is facilitated by the movement of one (in the present example- the front) clamping unit forward or backward. This allows a much simpler mechanical structure, since the need to change the length of the extensor module in a conventional inchworm MR complicates it. This simplification allows for a shorter and easier to miniaturize MR, which may comprise a hollow concentric tube along its main axis, for insertion of accessories, air or fluids, as described above.

It is appreciated that the clamping units grip the entire perimeter of the intestinal wall, thus affording a uniform pressure distribution and a wide gripping area that allows lower pressure, and avoiding points of a too high pressure on the intestinal wall.
It is also appreciated that there could be more than two clamping units, working in correlation to afford an inchworm-like propagation, resembling the well-known inchworm-like locomotion, though without the extension/contraction of the extensor modules, but rather as described here above for the two clamping units case.
It is also appreciated that two (or more) such MR main bodies could be attached in series via a flexible connection, to afford a different level of compliance with curves of the intestine, if needed. Such attachments could be facilitated by a flexible, hollow rubber tube, which thus also maintain the hollow tubular central opening through the MR body, as described above. In the case of two MR bodies attached in series, a specific configuration is that each of the two MR bodies comprises only one clamping unit, thus saving length while increasing flexibility.
It is further appreciated that other propagation principals and aids are described in the detailed description of this invention, and are also included in the scope of the invention.

The invention MR, as demonstrated by the embodiments in the detailed description here bellow, may comprise any, some or all of the following innovative features (whereas some of these features or combinations of them thereof, or all of them altogether, are not supported by prior art MR):

- A simple mechanical structure, which affords the needed miniaturization for passage through small-diameter ducts (e.g., the small intestine).
- A mechanical structure, in which all motorizing, control, supply elements and so, are positioned closer to the perimeter of the MR, thus allowing for a central, concentric hollow pipe in the MR along its longitudinal axis. This pipe may be used for insertion of conventional inspection, sampling, surgical and other accessories to the examined area ahead of the MR, and/or to inflate the intestine with air, as done in conventional endoscoy.
- A central, concentric hollow pipe passing through the MR along its longitudinal axis.
- A propagating method that resembles the inchworm locomotion, but does not include an extensor (or deformer) module between the two traction (namely clamping, gripping) modules, thus allowing for a simpler and more straightforward structure, which is easier to miniaturize and to comprise with a hollow central pipe for accessories/air insertion.
- A gripping mechanism that is substantially pressure driven rather than diameter driven, thus allowing to grip the interior walls of the intestine with a desired, known (tunable) pressure, regardless of the intestine's diameter at the gripped location.
- A gripping mechanism that supports a large variance of the intestinal diameter.
- A gripping mechanism that grips through a relatively large area of the intestine walls (e.g., a relatively wide perimetric ring contacting the intestine's interior circumference), thus allowing a strong enough gripping force through a low enough local pressure on the intestine's wall.
- An especially designed thin cover, which substantially isolates the MR from the intestinal environment, and which complies with the propagation sequence of the

MR (e.g., by having both substantially rigid and highly flexible segments to cover areas of the MR that are stationary or moving). In the above example, a rigid cover on the clamping units and a flexible cover on regions between them and between the front clamping unit and the head of the MR would be an appropriate choice.

It is appreciated that other features, variations and advantages of the present invention, as demonstrated by the described embodiments, would be apparent to one skilled in the art, though not explicitly noted here above, and should thus be considered in the scope of the invention.

THE INVENTION – DETAILED DESCRIPTION OF VARIOUS EMBODIMENTS

The present invention and the described embodiments are best understood with relation to the accompanying figures. It is appreciated that in some of the figures only the most relevant details are depicted, while some details and elements are omitted. It is also appreciated that in some of the figures, the correct ratio between elements in the figure is not necessarily maintained.

Fig.1 is a schematic side view of a MR encompassing the invention. Fig.2 is a front view of the MR of Fig.1. The MR **10** is generally composed of three major parts: a tail **20**, a head **30**, and a main body **40**. Preferably, the tail **20** and the head **30** are screwed into the main body **40**, as depicted schematically in Fig.4. This is very convenient for assembly of the MR, and for replacing heads that carry different tools and accessories, as needed for specific applications and operations.

The MR head **30** has a rounded and curved shape as seen in Fig.1, to assist in a smooth advancing within the internal intestinal walls **12**. The head carries the needed inspection, diagnostic and treatment tools and functionalities as discussed here above in the summary of the invention, such as a LED **32** and a CCD **34**, or any other needed accessory or tool. As seen in Fig.2, a concentric hollow tube **50** is passing through the whole length of the MR, from head to tail, enabling the insertion of accessories, air and liquids through the MR to the examined area of the intestine **14**, in front of the MR.

The tail **20** is connected (by any common means) to a flexible long bundle of tubes, cables and wires **60**, as described in details here above in the summary of the invention. Fig.3 is a schematic cross-section of an example bundle **60**. This bundle comprises a flexible tube **62** with a hollow duct **64**, a fiber optic **66** for optical signal or laser transmission, and four isolated electric wires **68** for electric signals, power and control transmission. The whole bundle is covered with a protective, electrically isolating, anti-friction Teflon thin coating **69**. The hollow duct **64** is utilized for passage of gases, fluids, vacuum, accessories and so from out of the intestine to the examined area of the intestine **14**, as well as to the MR itself, as required for its operation. The overall diameter of the bundle should be smaller than the smallest diameter of the internal wall of the intestine to

14, as well as to the MR itself, as required for its operation. The overall diameter of the bundle should be smaller than the smallest diameter of the internal wall of the intestine to pass through, and yet big enough to allow flexibility and accessories insertion. An example could be 3 to 6 millimeters diameter.

In a configuration wherein the MR itself includes a power source (e.g., a battery) and/or an electronic wireless/control/operation circuitry, these may be positioned within the tail **20**.

Further description of the elements within the tail is given after the description of the main body bellow.

The main body **40** of the MR is mainly responsible for the MR propagation mechanics. As seen in Fig.1 and Fig.2, the main body **40** comprises two clamping units, a front clamping-unit **42** and a rear clamping-unit **44**, which are encircling the main body. The rear clamping-unit is fixed around the main body, while the front clamping-unit is movable forward and backward along the main body, through a mechanical structure as depicted in Fig.5, which is across-section of the main body, taken through plain A-A' of Fig.2.

As seen in Fig.5, rear clamping-unit **44** is made of a ring-shaped rigid element **72**, encircling the main body, to which a flexible, inflatable annular balloon **74** is connected. The balloon **74** could be inflated with air or deflated from air (corresponding to the "extended" and "contracted" states respectively, as described above in the summary of the invention), through a tube, which is not shown in Fig.5 but will be described bellow. When inflated, the balloon may have a substantially rectangular shape as depicted, rather than circular cross-section, to afford saving longitudinal space and to allow gripping of the intestinal wall by a larger area. The balloon is preferably constructed with very low resistance to air inflation (namely very easily stretchable towards the intestinal walls), thus the pressure in the inflated balloon is approximately the gripping pressure of the intestinal walls, independently of the intestine's diameter. This allows for gripping with a known pressure, regardless of the intestinal diameter. Nevertheless, even if the inflation resistance of the balloon could not be neglected with respect to the gripping pressure, it could be well-known (being a property of the balloon), allowing the net pressure on the intestine to be calculated through the total supplied pressure and the intestinal diameter, as measured separately (for example, by analyzing the images retrieved from the MR head). Thus, a well-determined, tunable pressure can be applied on the intestinal walls regardless of their internal diameter. The balloon, as reflected from Fig.5, also allows a relatively wide gripping area, preventing high local forces on the intestine. It is also appreciated that the balloon grips the entire internal perimeter of the intestine.

Similarly, front clamping-unit **42** is made of a ring-shaped rigid element **76**, encircling the main body's cylindrical envelope **38**, to which a flexible, inflatable annular balloon **78** is connected. The balloon **78** could also be inflated with air or deflated from air, through a tube, which will be described bellow. The description here above of the rear balloon **74** also applies for the front balloon **78**. The movement of the front clamping-unit is facilitated through two pneumatic cylinders **82** and **84**, located within the main body's

cylindrical envelope **38** at the top and bottom of the main body, respectively. The piston of each cylinder has a right angle extension at its front edge, extending out of the main body's envelope **38** through corresponding longitudinal slots **86** and **88**, in the top and bottom of the main body's envelope respectively. The pistons are connected to the internal perimeter of the ring-shaped rigid element **76**. At the front of each cylinder is a small opening **90**, not accessible to the cylinder's air behind the piston (namely to the right of the piston). These openings connect the front cavity of each cylinder with the environmental air, fixing its pressure to about atmospheric pressure. The cylindrical cavities of the top and bottom cylinders behind the pistons are fed by pneumatic tubes **92** and **94**, respectively, with either high pressure or vacuum. The pneumatic tubes **92** and **94** are connected to each other in the rear region of the main body 40, and fed by the same supply line of either high pressure or vacuum, coming from an out-of-body external supply, through the hollow duct **64** and through the tail. A forward movement of the front clamping-unit **42** is facilitated by feeding the pneumatic line with high pressure (namely higher than the environmental pressure at the front of the piston). A backward movement of the front clamping-unit **42** is facilitated by feeding the pneumatic line with vacuum or low pressure (namely lower than the environmental pressure at the front of the piston). It is appreciated that after a forward or backward movement is completed, a valve in the tail (to be described here bellow) may close the pneumatic line connection to the tubes **92** and **94**, thus maintaining the high or low pressure behind the piston, respectively, and hence locking the cylinders and preventing unwanted movement.

Also seen in Fig.5 is the empty cylindrical cavity **50**, passing through the whole length of the MR, which is separated from the peripheral mechanics of the main body by a cylindrical hollow tube **52**.

An alternative to applying vacuum or low pressure for moving the piston backwards is a returning spring **98**, which pushes the piston away, as well known in the art. In this case, the high pressure in the back of the piston works against the spring for pushing the piston forward. This alternative is schematically depicted in Fig.6. For simplicity, only the upper half of the main body's cross-section is depicted, acknowledging that the lower half resembles the upper half, as in Fig.5. It is appreciated that other variations are also applicable, as will be apparent to one skilled in the art, and are thus in the scope of the invention.

It is appreciated that instead of the above describe configuration, the cylinders could be operated conventionally, as well known in the art, through both high-pressure lines and low-pressure lines. However, the above described configurations afford both forward and backward motion of the cylinders through a single pneumatic line, which simplify the operation mechanism, and allows feeding of the pneumatics through the flexible tubular duct **62**, which is also used for accessories insertion, thus saving dedicated pneumatic lines, simplifying the MR and affording a thinner and more flexible bundle **60**.

It is further appreciated that the front clamping-unit may be moved forward and backward by any alternative mechanism, as well known in the art, as long as the spirit of the invention is maintained.

Fig.7 depicts an alternative movement method, in which the piston is moved either forward or backward electro-magnetically (e.g., by a solenoid carrying appropriate electric current) rather than pneumatically, as well known in the art. Fig.7 (a) is an alternate with a returning spring, and Fig.7 (b) is an alternate without a returning spring. It is noted in this respect, that the rubber stretchable cover of the MR, which is described in details bellow, could also be utilized as a returning mechanism for the front clamping-unit, instead of a returning spring.
Fig.8 depicts yet another alternative movement method, in which a rotary motion of a micro-motor is transformed to either a forward or backward linear motion of the front clamping-unit, through a rubber band, chain or the like, to which the front clamping-unit is attached through the longitudinal slot.

Fig.9 is a cross-section of the main body **40**, taken through plain B-B' of Fig.2, showing schematically the pneumatic tubes used for inflation and deflation of the inflatable balloons. The high or low air pressure (or vacuum) is supplied to the balloons **74** and **78** of the rear and front clamping-units separately, via corresponding pneumatic tubes **102** and **104**, respectively. An appropriate separate holder **105** mounts each of these tubes to the main body's cylindrical envelope **38**. The tube **102** of the rear balloon **74** penetrates through the holder **105a**, the main body's cylindrical envelope **38**, and the ring-shaped rigid element **72**, into the internal volume of the inflatable balloon **74**. The tube of the front balloon **78** is mounted by holder **105b**. The continuation of this tube **110**, between the holder **105b** and the balloon **78**, is flexible, thus accommodating the forward and backward longitudinal motion of the front clamping-unit. It extends out of the main body's cylindrical envelope **38** through an appropriate longitudinal slot **112**, and through the ring-shaped rigid element **76**, into the internal volume of the inflatable balloon **78**.
Fig.10 depicts a variation of Fig.9, wherein a telescopic tube is used instead of the flexible tube **110**. It is appreciated that various other alternatives are applicable for pneumatic supply to the non-stationary front inflatable balloon **78**, as apparent to one skilled in the art, and are thus considered within the scope of the invention.

Fig.11 schematically depicts the forward propagation (advancing) sequence of the MR, based upon the contraction/extension states of the inflatable balloons and the forward/backward states of the front clamping unit, as described in the appropriate steps 1 to 7 at the summary of the invention above, which consequence a single advancing step of the MR.
Fig.12 schematically depicts the backward propagation (retracting) sequence of the MR, based upon the contraction/extension states of the inflatable balloons and the forward/backward states of the front clamping unit, as described in the appropriate steps 1 to 7 at the summary of the invention above, which consequence a single retracting step of the MR.
As demonstrated in Fig.11 and Fig.12, the propagation of the MR is somewhat resembling an inchworm-like locomotion, but it does NOT utilize a length change of an extensor module that mediates the two clamping units (in the present MR, that would have been a length change of the main body 40), but rather the propagation is facilitated by relative movement of the clamping units, whereas the length of the mediating module (that is the main body) is unchanged.

It is appreciated that there are alternative methods and constructions for affording the clamping-units' "extended" and "contracted" states, apart from the inflatable balloons described above.

An example of another mechanism for clamp extension/contraction is schematically depicted in Fig.13 and Fig.14. Fig.13 is a rough front cross-section of either the front or rear clamping-unit. Instead of an inflatable balloon, it comprises a ring-shaped, flexible, stretchable rubber band **130**, which encircles two clamps **132a** and **132b**, of a half-ring shape. The rubber band **130** squeezes the two clamps **132** against the main body's cylindrical envelope **38**, in the contracted state, as depicted in Fig.13(a). Top and bottom extendable cantilevers **134a** and **134b**, respectively, are extending out of the envelope **38** through appropriate longitudinal slots in the envelope **38**, and are attached to the clamping units **132a** and **132b**, respectively. The inner ends of the cantilevers **134** are attached to appropriate mechanical actuators **136a** and **136b**, which can extend the cantilevers that in return push the clamping units outwards, while stretching the rubber band **130** and yielding the extended state, as depicted in Fig.13(b).

Fig.14 is a rough longitudinal cross-section of the clamping unit and main body. It shows the mechanical actuator **136a**, which comprises an electromagnetic cylinder **138** and corresponding piston **140** for extending the cantilever **134a**, by pulling its two halves towards each other, as shown by arrows in the figure. The cantilever may be connected to the main body via the pivot **142**, or through the cylinder **138** (whose connection to the main body is not shown in the figure), or else.

The tail **20** acts as a the distribution center of all the electronic, optic, pneumatic and like wiring, cables and signals. The various wires, cables and tubes are connected to its rear end by any suitable, well-known means. They are passing through the tail, and to their appropriate locations in the MR (e.g., the fiber optic goes to the front of the head **30**, the pneumatic pressure/vacuum is split to the various channels in the main body **40**, electric wires go to the head for illumination and to the electro-magnetic cylinders/motors in the main body, as needed, etc). The tail is also in-charge of dividing the signals, controls and pneumatics between the appropriate channels, as needed. This could be done by any switches, valves and the like, as well known in the art. Fig. 15 schematically depicts an example cross-section of a tail **20**, showing various alternative connections between the rear hollow duct **64** and inlet tubes for pneumatics and else. The switching between the alternative connections is done by a cylindrical valve **150**, which in this example has four states (a) to (d), as depicted in Figs.15(a) to 15(b), respectively:

(a) The central hollow tube **50** of the MR is open, and available for insertion of accessories or air to the front of the intestine **14**

(b) The duct **64** is channeled to the tube that delivers pneumatic pressure/vacuum to the cylinders **82** and **84**, through tubes **92** and **94**, for moving the front clamping unit **42** forward or backward.

(c) The duct **64** is channeled to the tube that delivers pneumatic pressure/vacuum to the rear inflatable balloon **74**, through tube **102**.

(d) The duct **64** is channeled to the tube that delivers pneumatic pressure/vacuum to the front inflatable balloon **78**, through tube **104**.

Turning the valve **150** to the desired state could be done by any method as well known in the art, such as a rotary electro-magnetic actuator that works against an applied moment of a rotary spring, as schematically illustrated in Fig.16, whereas Fig.16(a) is a front view and Fig.16(b) is a side view. Other alternative switching mechanisms and valves shapes and configurations could be applied, as well known in the art. Fig.17 depicts an example of a linear valve, switched through an electro-magnetic cylinder that works against a linear spring. Switching could be facilitated through a micro-motor, located appropriately in the tail, though electro-magnetic actuators and the like may have the advantage of simplicity and ease of miniaturization.

It is appreciated that a four-state valve is just an example, and valves with different number of states could be realized similarly. For example, a fifth "emergency" state is optional, in which both inflatable balloons are connected to the central tube and hence to ambient pressure. In such a state, both balloons are deflated from air, and the MR could be pulled out of the intestine easily through the rear bundle, in the case of a failure that disables the MR propagation ability. It is further appreciated that this "emergency" state could be the free state of the valve, namely which no external control is required for maintaining it. For example, in the case of an electro-magnetic cylinder that works against a spring, the emergency state should be the state with no electric current in the electro-magnetic cylinder. Thus, in case of failure, the MR would naturally switch to this state, facilitating its pullout.

ADDITIONAL ACCESSORIES, ALTERNATIVES AND DEVICES

Any accessory for insertion through the hollow duct **64** could include a wider neck **160** of diameter equal or close to the diameter of the hollow duct **64**, as depicted in Fig.18. This allows easier insertion/extraction of the accessory, mostly if the MR has propagated a long way through the intestine, passing through many intestinal turns. By applying over pressure in the hollow duct **64** before the accessory neck **160**, the accessory is pushed forward toward the MR. By applying vacuum before the accessory neck **160**, the accessory is drawn backwards towards the opening of the intestine.

For any treatment of the intestine in front of the MR via an inserted accessory, laser beam etc, the two clamping units 42 and 44 could be both turned to extended position, thus gripping the intestinal walls both at the rear and front of the main body, and stabilizing the MR against the intestine. Such stabilization is not achievable with conventional endoscopes, which do not grip the intestine.

Optionally, the MR could possess a configuration for exposing a local area of the intestine to a needed fluid (e.g., liquid medicine, analytical solution, cleaning solution, etc). This could be facilitated by an additional state of the valve **150** (or the like) in the tail, which connects the hollow duct **64** to a tube **170** in the main body, which is extending out of the main body's envelope **38** through an appropriate opening. When the main body **40** is in the location of the intestinal wall that should be exposed to the liquid,

the two balloons are inflated, as depicted in Fig.19. This confines an intestinal ring around the main body, and isolates it from the rest of the intestine, blocking liquid from passing through. Next, the valve is switched to the state in which the hollow duct **64** is connected to the tube **170**, and the appropriate liquid is inserted through the hollow duct **64**, until it reaches the confined intestinal ring. The hollow duct **64** could be depleted from air by vacuum prior to liquid insertion. After treatment, the liquid is drawn out by vacuum.

It is appreciated that the rear bundle, and particularly the flexible tube **62**, could be made of a substantially flexible material, such as thin rubber, and thus could be fully depleted from gas or liquid by vacuum. This is beneficial for changing between gases and liquids that are inserted to the front of the intestine **14** or to the confined area as described here above, for intestine inflation, therapeutic treatments, etc.

It is optional to cover the MR with a protective cover. This is beneficial for isolating the MR from the intestinal environment, thus preventing intestinal substances from contaminating and ruining the MR and penetrating its interior, which may disturb its operation. This also eliminates or reduces the need for cleaning and sterilization of the MR between patients, and reduces patient-to-patient infection. Such a cover could be reusable, or a single-use, disposable cover. It is appreciated that the cover should be made of a thin layer, which is resistant to the intestinal fluids, such as a chemical resistant polymeric coating, e.g., as used in chemical laboratory gloves, or so, as well known in the art. It is further appreciated that the cover should comply with the propagation mechanism of the MR, not disturbing its mechanical operation and sequence, or even helping it. This could be achieved, for example, by constructing the cover from alternating semi-rigid and very flexible regions, as required by the moving parts of the MR (e.g., the inflation/deflation of the front and rear balloons, and the forward/backward movement of the front clamping unit). Thus, the annular areas of the cover above the balloons should afford the radial expansion of the balloons during inflation, and the annular areas of the cover between the two clamping units and between the front clamping unit and the head should be very stretchable, thus affording the forward and backward motion of the front clamping unit. Attachment of the cover to the balloons could be achieved by the semi-rigid, less flexible nature of the cover around the balloons, or by attachment of the balloon and the cover via a double-sided adhesive tape, or by any conventional means. It is noted that conventional polymeric techniques allow a polymeric layer to be stretchable in one direction, while not stretchable in the perpendicular direction. This could be utilized in the cover areas around the balloons, allowing the cover's diameter to be stretched easily and increased as needed to accommodate the balloon's inflation, while being relatively not stretchable in the longitudinal direction, preventing relative movement of the balloon and cover, in the area around the balloon. The cover should also comply with the functionalities and accessories of the MR, as required by the MR operation and endoscopy needs. Hence, the cover may be stretched and attached around the perimeter of the MR head, while having a circular hole in its front center, to allow good attachment to and sealing of the MR, while affording insertion of accessories, air and liquids through the MR head to the intestine. If no accessory insertion is needed, the front of the cover may be continuous, but made of an optical

window (e.g., a transparent polymeric material) to afford lighting of the intestine, collection of optical signals and images, and laser treatment of the intestine without absorption or diffusing of the laser light by the cover. The optical window may be implemented with a circular front opening, if needed. It is appreciated that the stretchability of the cover could be utilized as a returning force for working as a counter force to the backward/forward cylinders and/or the balloons inflation. Thus, the cover could act as a spring for returning the front clamping unit to its original state (e.g., forward), when the cylinder is releasing power, and/or as a deflating force, which deflates the balloons when they are connected to ambient air. It is further noted that the outer walls of the cover may be designed to assist the propagation of the MR, e.g., by affording a sticky or rough or dandruff-covered surface in the clamping units area for good gripping of the intestine, while affording a frictionless surface at the front of the cover, to allow smooth propagation of the MR head. An example of a cover is schematically depicted in Fig.20. Fig. 20(a) depicts the cover in its natural, relaxed state, prior to covering the MR. Fig. 20(b) roughly depicts the cover on the MR, with both balloons inflated and front clamping unit in rear position. Fig. 20(c) roughly depicts the cover on the MR, with both balloons inflated and front clamping unit in front position.

The MR may be comprised of two or more basic MR units as described above, to afford better steering and propagation through sharp curves of the intestine, whereas each two MR units **10** are connected to each other by a flexible, bendable hollow tube **180** (e.g., a rubber pipe), to afford bending of the structure alongside a hollow central tube for accessories and air insertion, as discussed above. This is roughly depicted in Fig.21(a). Alternatively, the structure could be made of two half-micro-robots, as roughly depicted in Fig.21(b), whereas the rear half includes the tail and the rear clamping-unit, which is stationary with respect to the main body, and the front half includes the head and the front clamping unit, which is movable forward and backward with respect to the main body. As in the previous case of Fig.21(a), the two MR halves are connected via a hollow, bendable rubber pipe. Yet another alternative is roughly depicted in Fig.21(c), in which a bendable, hollow rubber tube **190** is connected to the MR head, to assist propagation through sharp curves. When the structure approaches a curve, the bendable front tube is bending to comply with the intestinal curvature, as demonstrated in Fig.21(c). This, in turn, generates a side force (namely a torque) on the MR, and gently forces it and directs it to comply with the curvature as well. It is appreciated that the external diameter of the rubber tube **190** is smaller than the head's diameter, therefore not disturbing the illumination and imaging of the intestine with the head's accessories as described above. Alternatively, the rubber tube **190** may carry some or all of the above mentioned accessories and tools at its front portion, instead of the head. It is also appreciated that the rubber tube could be coated with an anti-sticking or non-friction coating (e.g., Teflon), to allow smooth propagation while pressing (gently) against the intestine's walls when passing through intestinal curves.

In various cases it might be desired to pre-examine the interior of the intestine by taking a laboratory sample or a biopsy, prior to (or instead of, or in addition to) performing an endoscopic procedure. This could be facilitated through a long and narrow accessory, which is inserted into the intestine through the rectum (after an appropriate cleaning

procedure of the interior of the relevant portion of the colon, as needed and by common methods, as well-known in the art), and takes relevant sampling or biopsy of the colon's interior. This could be a sampling of the colon wall's substances, fluids etc., or a superficial biopsy of the colon's internal walls, or the like. An example of such a sampling accessory **200** is depicted in Fig.22. It comprises a base **210** and a long, narrow, and flexible syringe-like unit **220**, which is composed of an external tube **222** and a concentric, internal cylinder **224**. Fig.22(a) is a side view of the device in its original position, prior to inserting into the colon. Fig.22(b) is a schematic side cross-section of the device, after inserted into the colon to its full required length. The base is thick enough to remain out of the body, while the syringe-like unit is gently pushed into the colon through the external tube **222**. In this stage, the syringe-like unit **220** is yet in its original position, in which the handles of the external tube **222** and the internal cylinder **224** are separated from each other, thus keeping the sampling arms **230** of the internal cylinder inside the external tube **222**. After the unit **222** has been inserted into the colon, the handles of the syringe-like unit **222** are brought closely together (like when injecting with a conventional syringe), as seen in Fig.22(c). This extends the sampling arms **230** out of the external tube **222**. The sampling arms **230** are made of a flexible material, and their natural, relaxed state is diagonal to the main axis of the cylinder **224** (namely, they are forced into the external tube **222** in the device's original state, as in Fig.22(a) and Fig.22(b)). Thus, the extended sampling arms relax back to their diagonal position, gently pressing the colon's internal walls, as seen in Fig.22(c). The amount of force applied by the sampling arms **230** on the colon is pre-tuned, through the arms' material (plastic, metal strip, etc), the mechanical parameters, the length of the arms, the angle between the arm in its fully relaxed state and the cylinder **224**, and so. This force is correlated to the sampling nature. The shape and nature of the edges of the sampling arms **230** is also related to the sampling nature and conditions. In the example of Fig.22, the arms' edge is a sharp edge, which gently scratches the colon's internal surface for taking a superficial biopsy. Alternatively, the edge could comprise an absorbing layer for taking sample of the colon's substances, or else. It is appreciated that there is a plurality of sampling arms **230**, of which only two are seen in the cross-section of Fig.22. Alternatively to a plurality of discrete sampling arms, a cone-shaped sampling unit could be utilized, thus sampling the whole internal circumference of the colon. After the sampling arms are extended and touching the colon, the syringe-like unit **220** is drugged out, by pulling the external tube **222**. During the unit **220** pullout, the sampling arms take the relevant samples of the colon, and store it within the arms' edge. When the unit **220** is fully pulled out, the syringe-like unit is stopped by the base **210**, through any common stopper, which is not shown in Fig.22. In this final state, the sampling arms are inserted within the base, as shown in Fig.22(d), hence securing the sample **240**, which is taken to the laboratory for appropriate analysis.

The length of the syringe-like unit could be pre-designed to fit the required sampling depth in the colon. The external diameter of tube **222** is small enough to allow insertion into the colon. The syringe-like unit **220** should be smooth and flexible enough, to allow insertion into the colon without causing a considerable pain to the patient, and without damaging the colon's walls. It is appreciated that the above-described device **200** (or any accessory of a similar nature) could be used by a physician, or be appropriate for self-use by the patient. This would have many advantages, such as performing the sampling

procedure in private, at the patient's own convenience, reducing load from the medical services, and turning the procedure to a simple lab test, as common urine collection for lab analysis etc.

Fig 1:

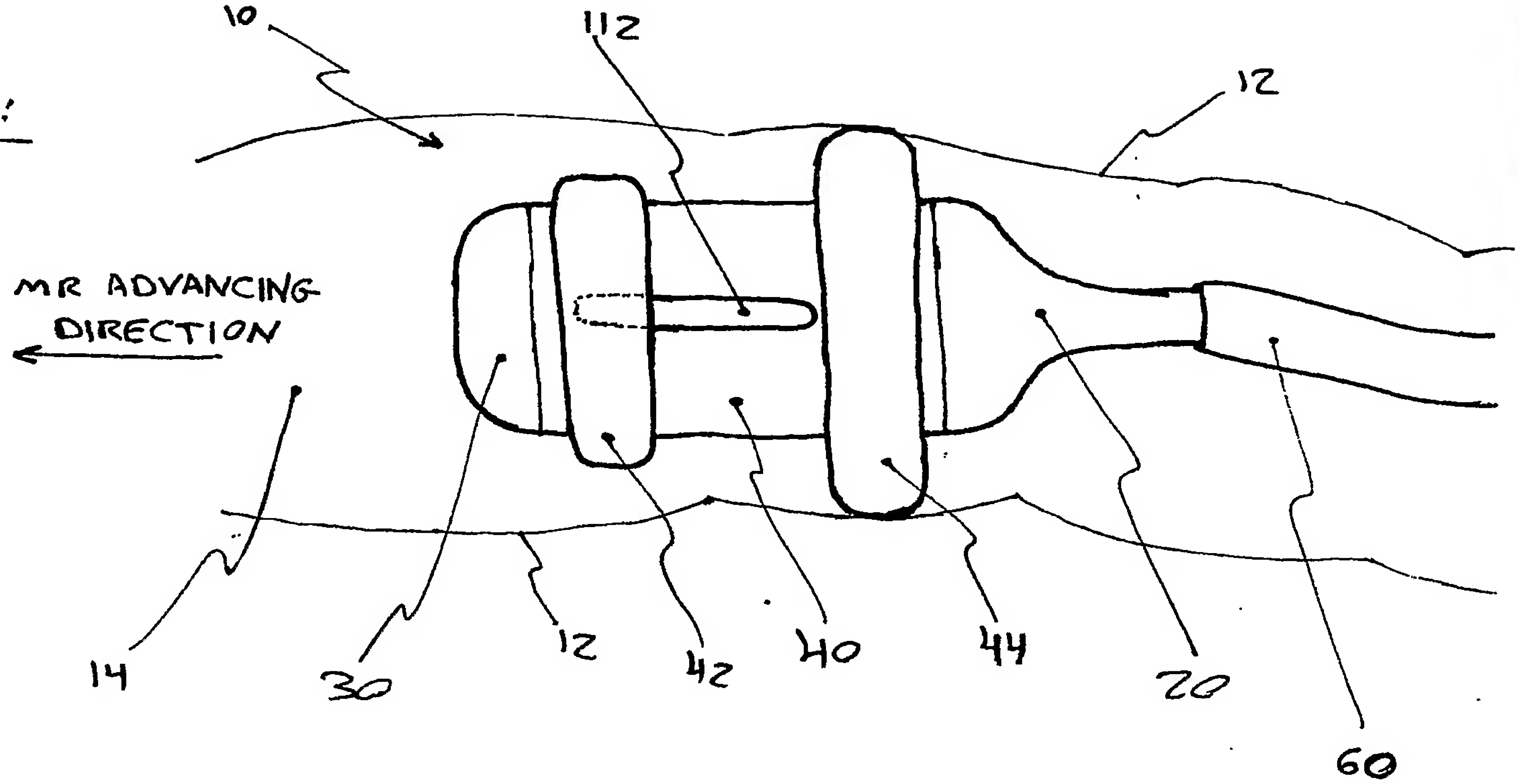

10
112
12
MR ADVANCING
DIRECTION
14
30
12
42
40
44
20
60

Fig 2:

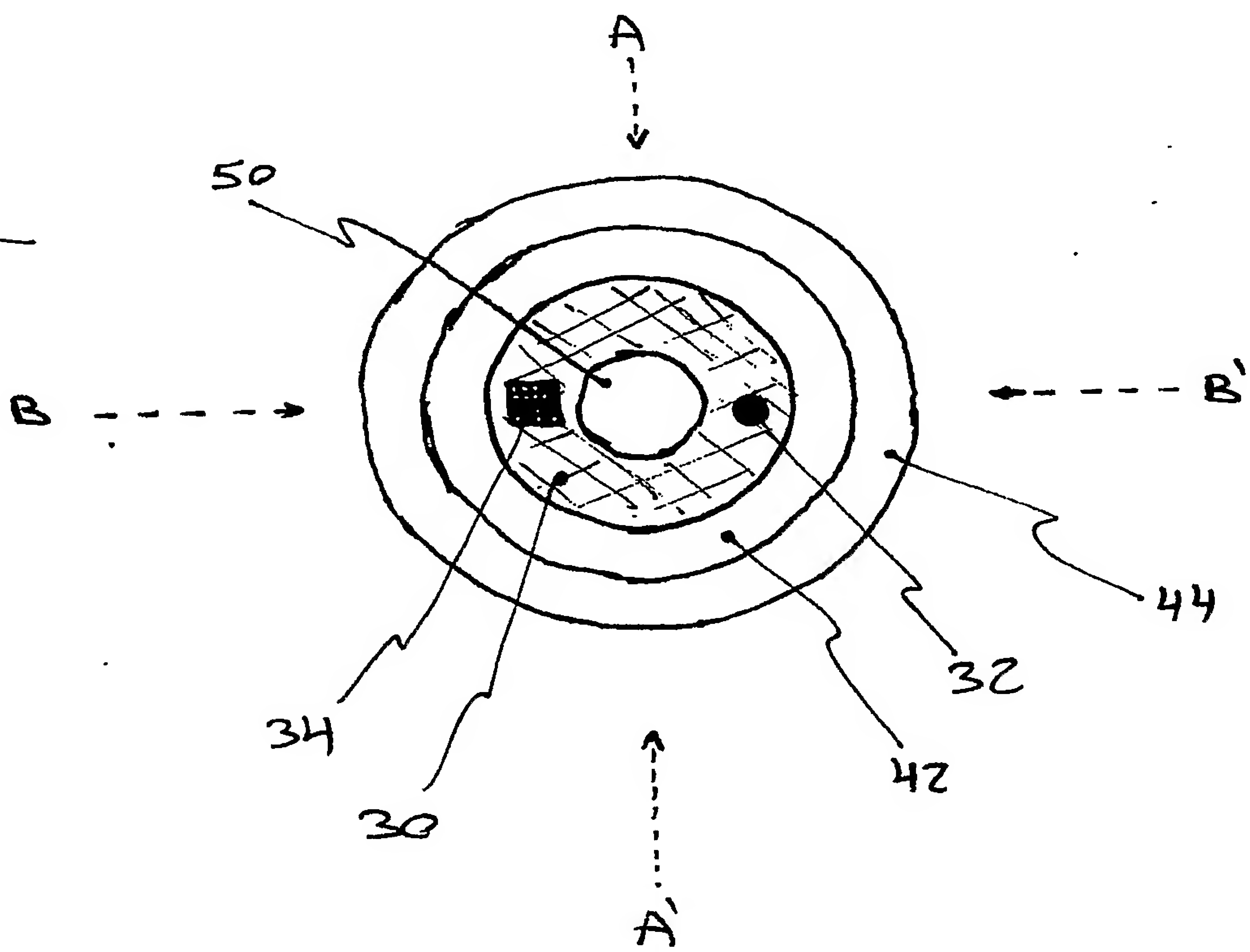

A
50
B
B'
44
32
34
42
30
A'

Fig. 3:

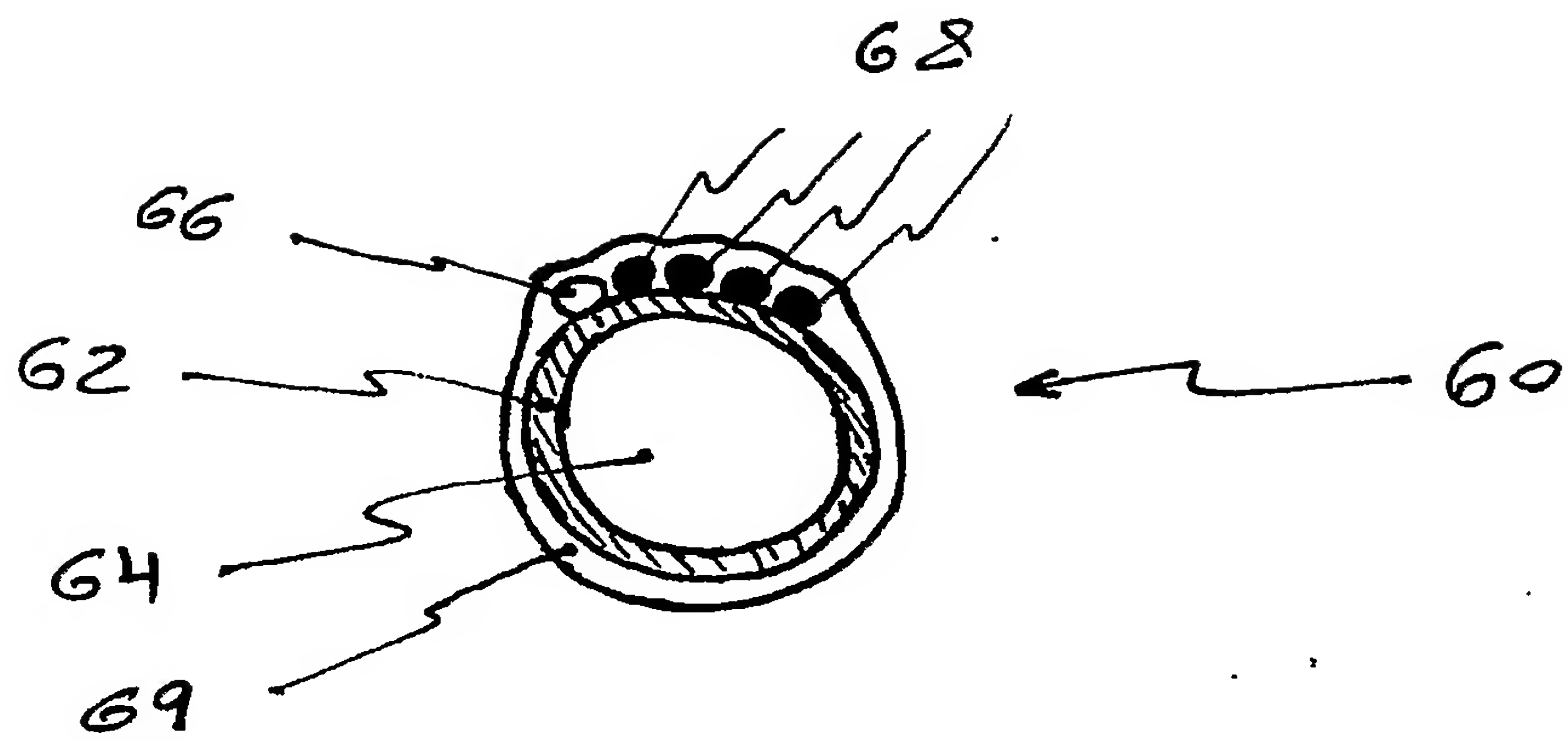


Fig. 4:

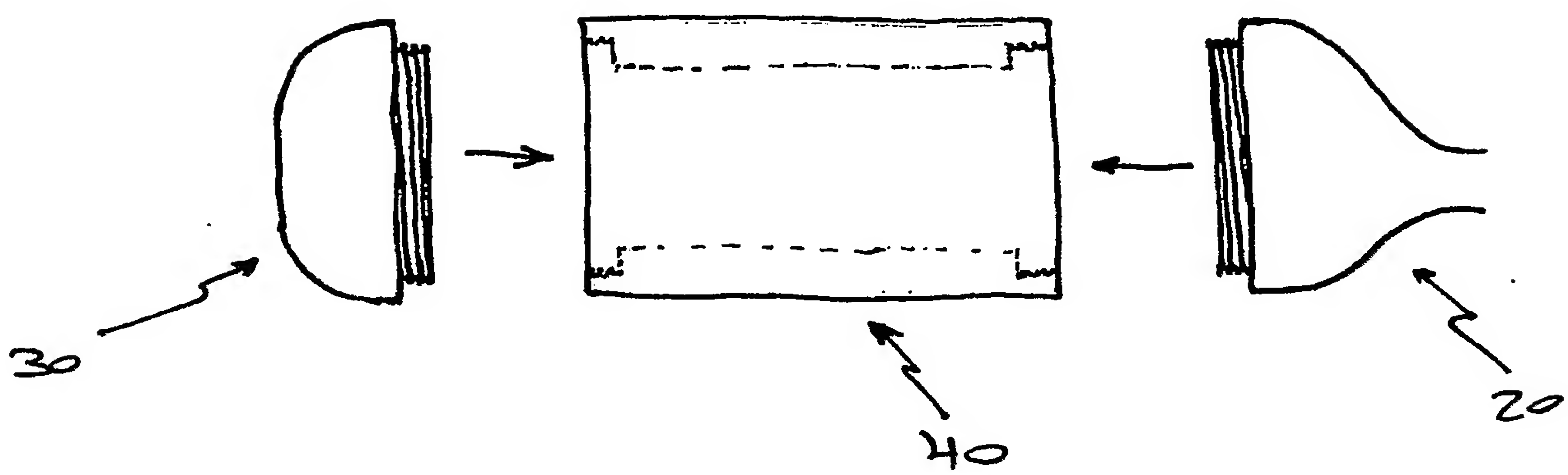


Fig. 5:

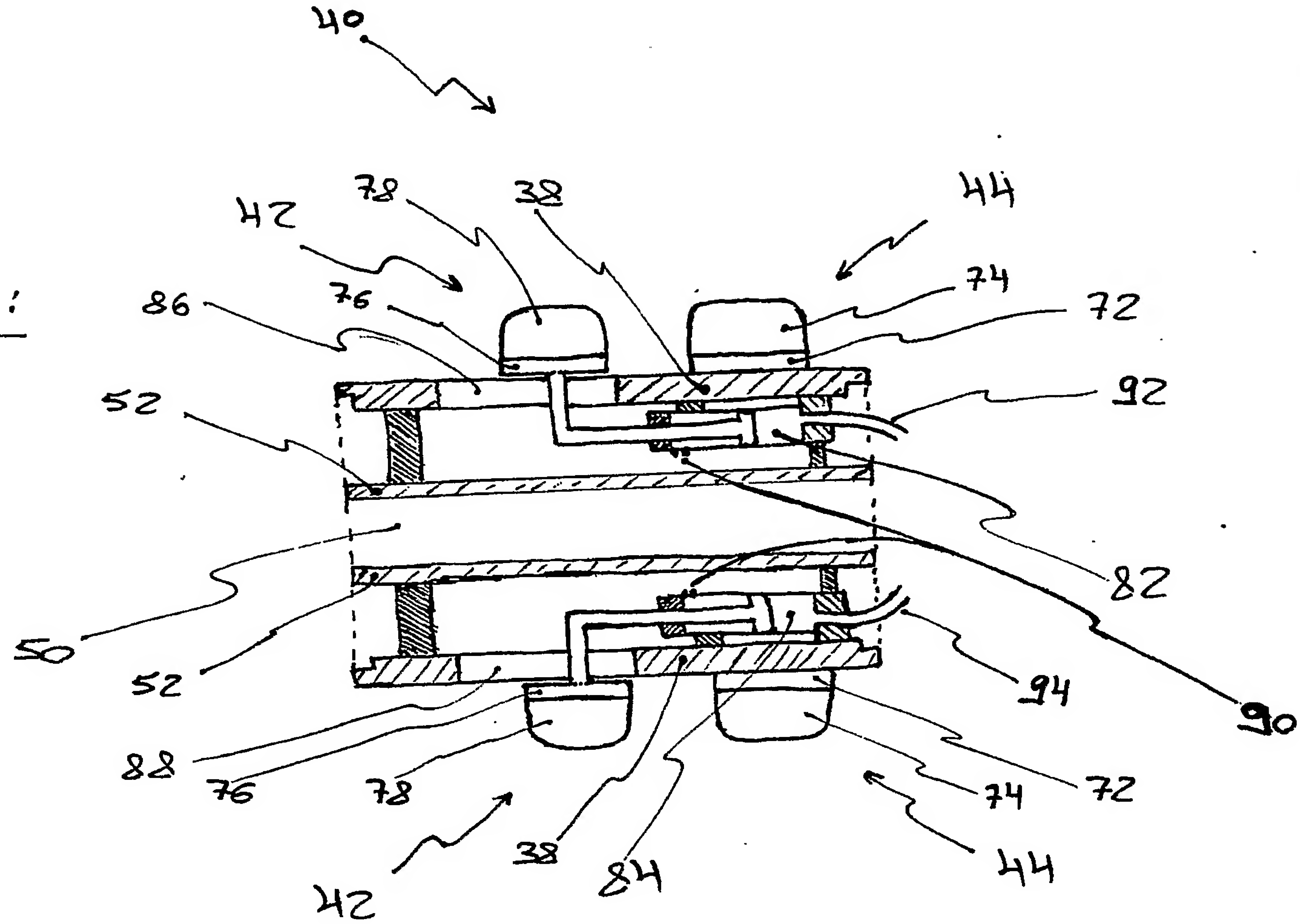

40
42
78
38
44
74
72
86
76
92
52
82
50
52
90
94
88
76
78
74
72
38
84
44
42

Fig. 6:

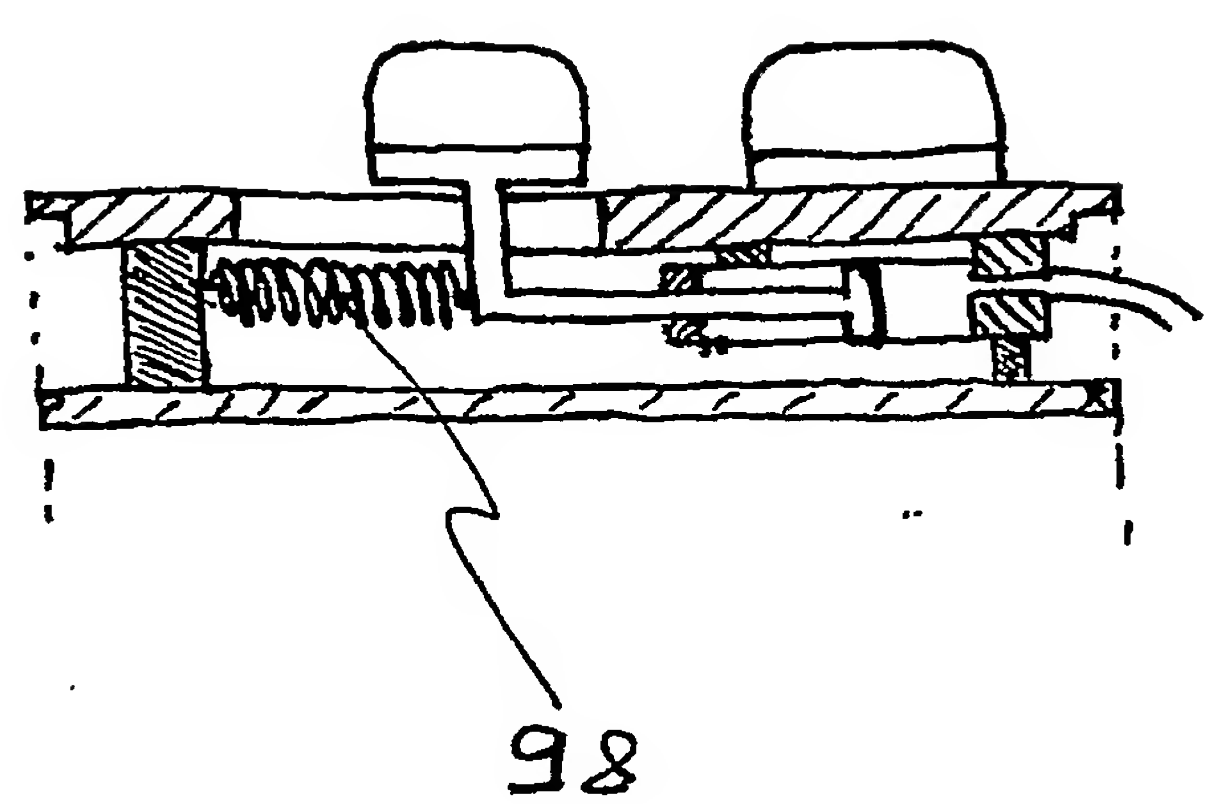
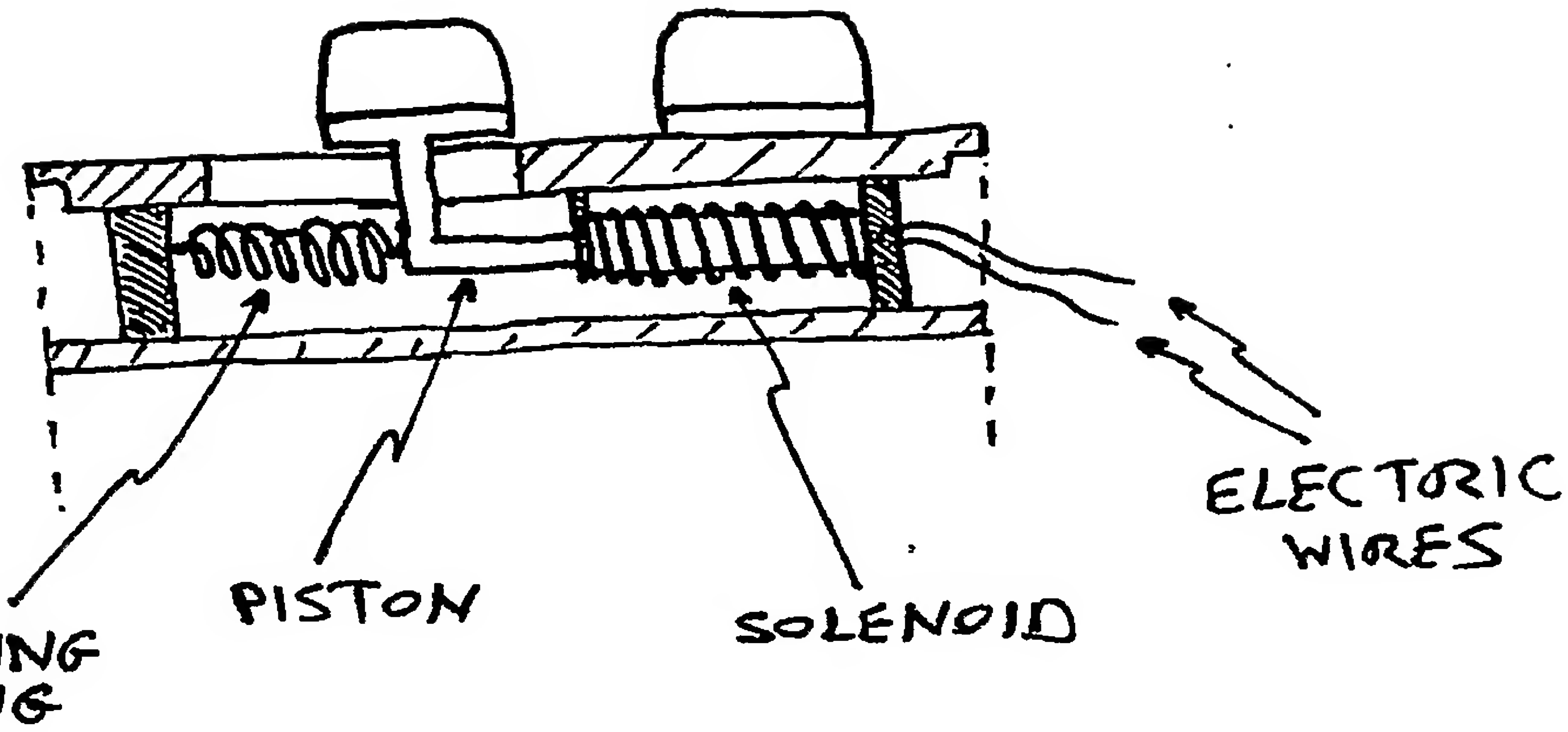

98

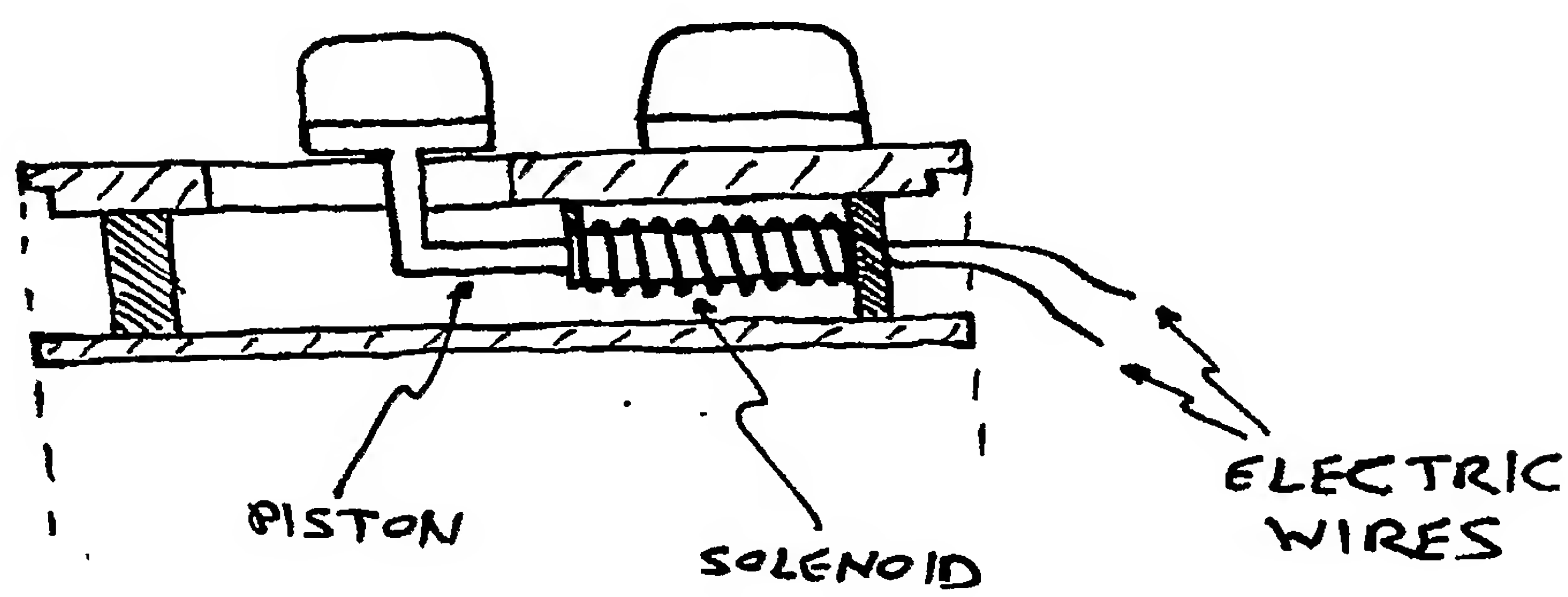
Fig 7:

(a):



ELECTRIC
WIRES
PISTON
SOLENOID
RETURNING
SPRING

(b):



ELECTRIC
WIRES
PISTON
SOLENOID

Fig. 8:

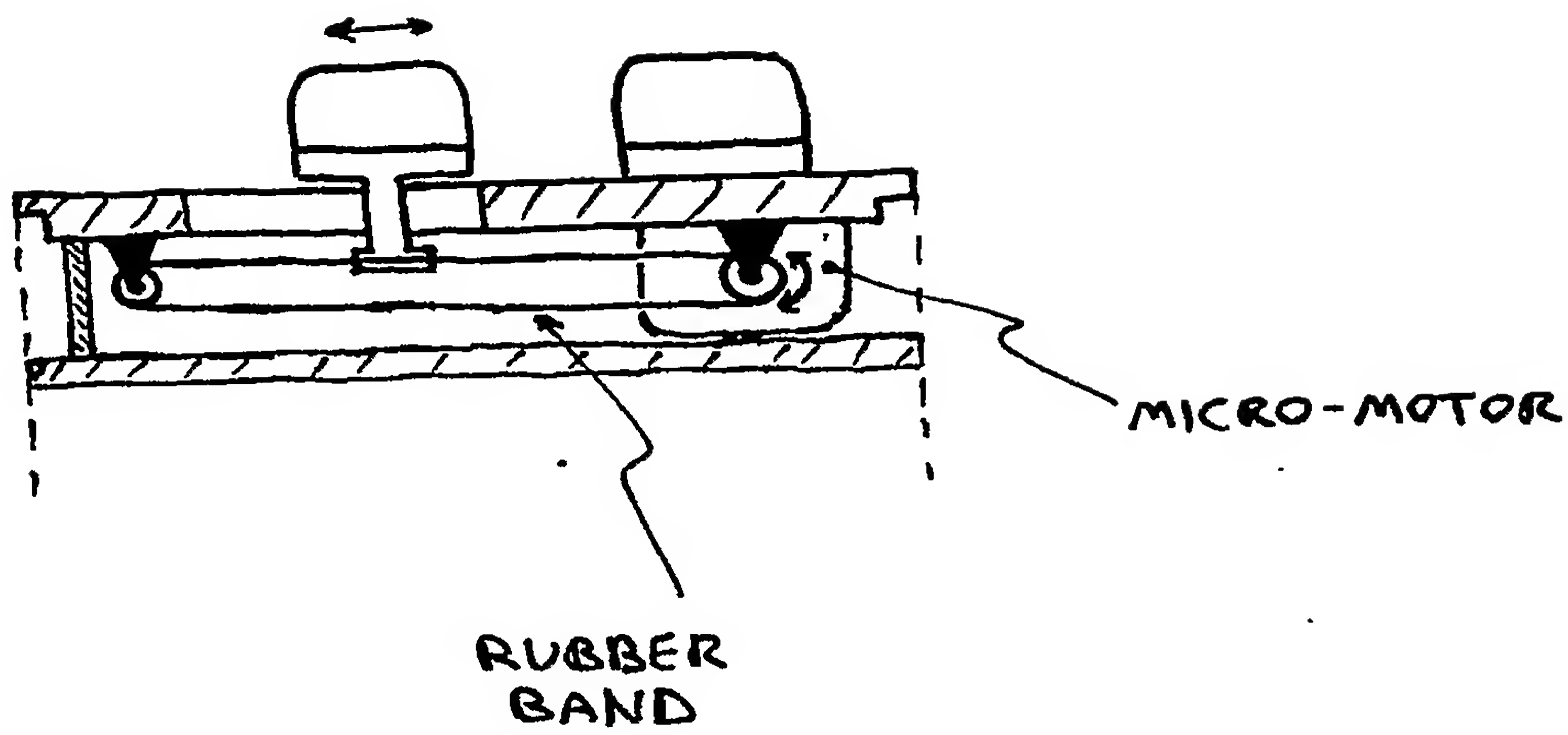


Fig. 9:

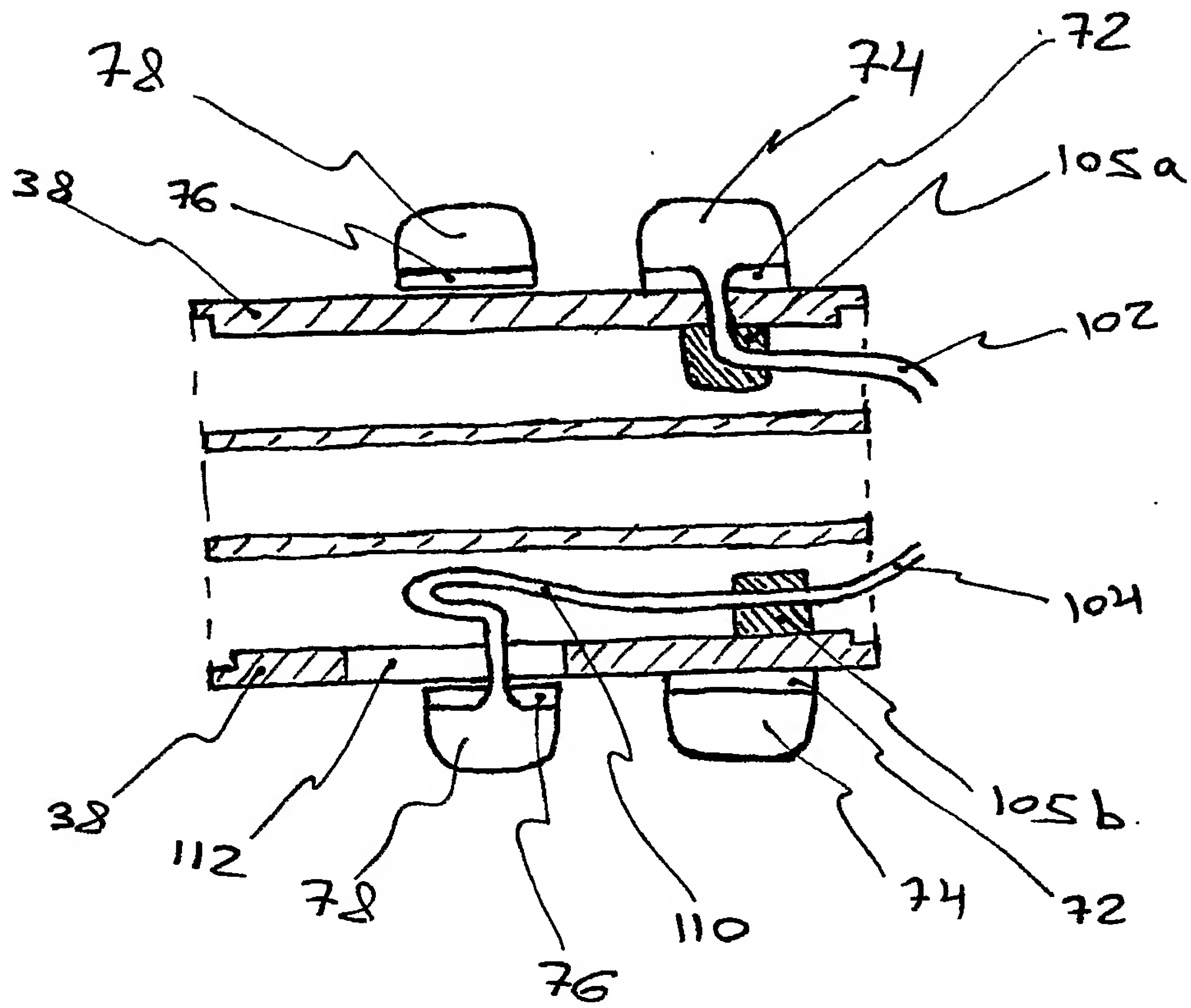
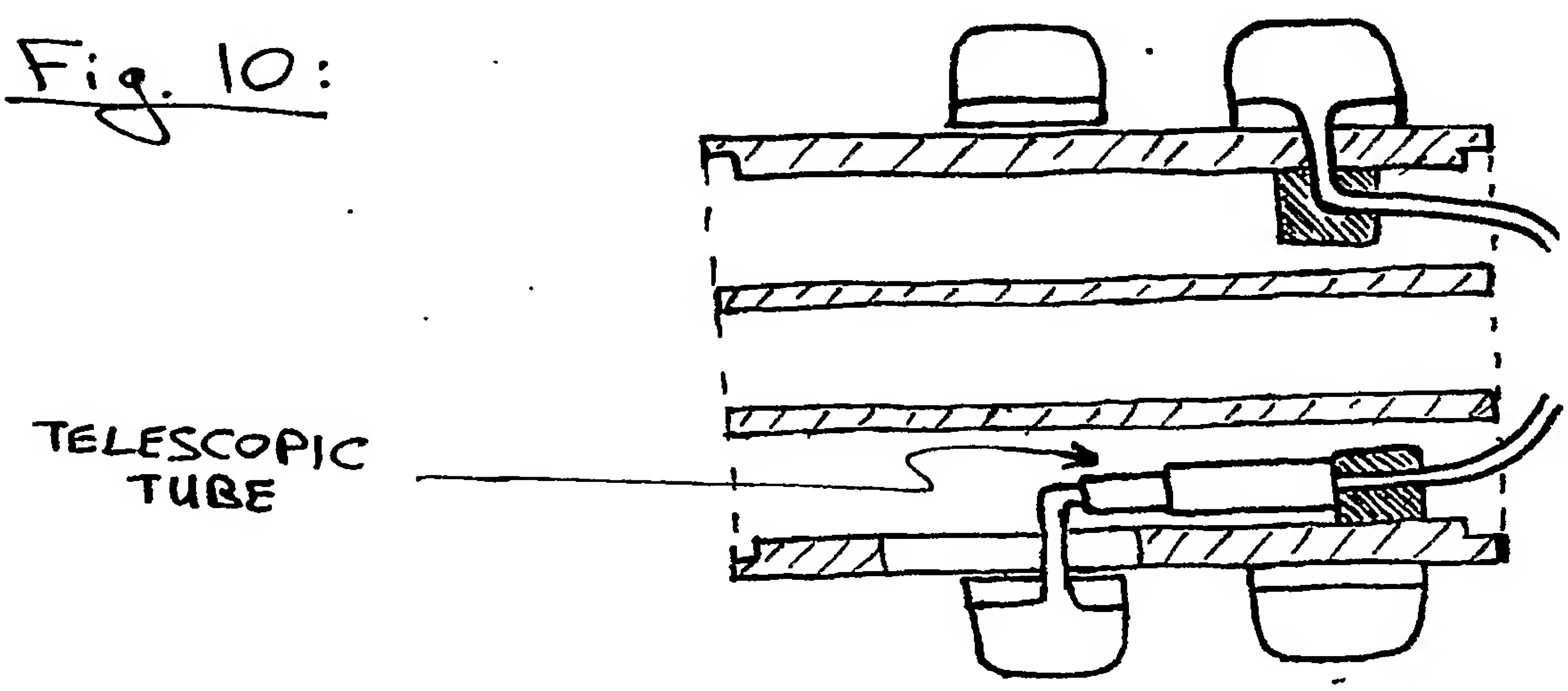
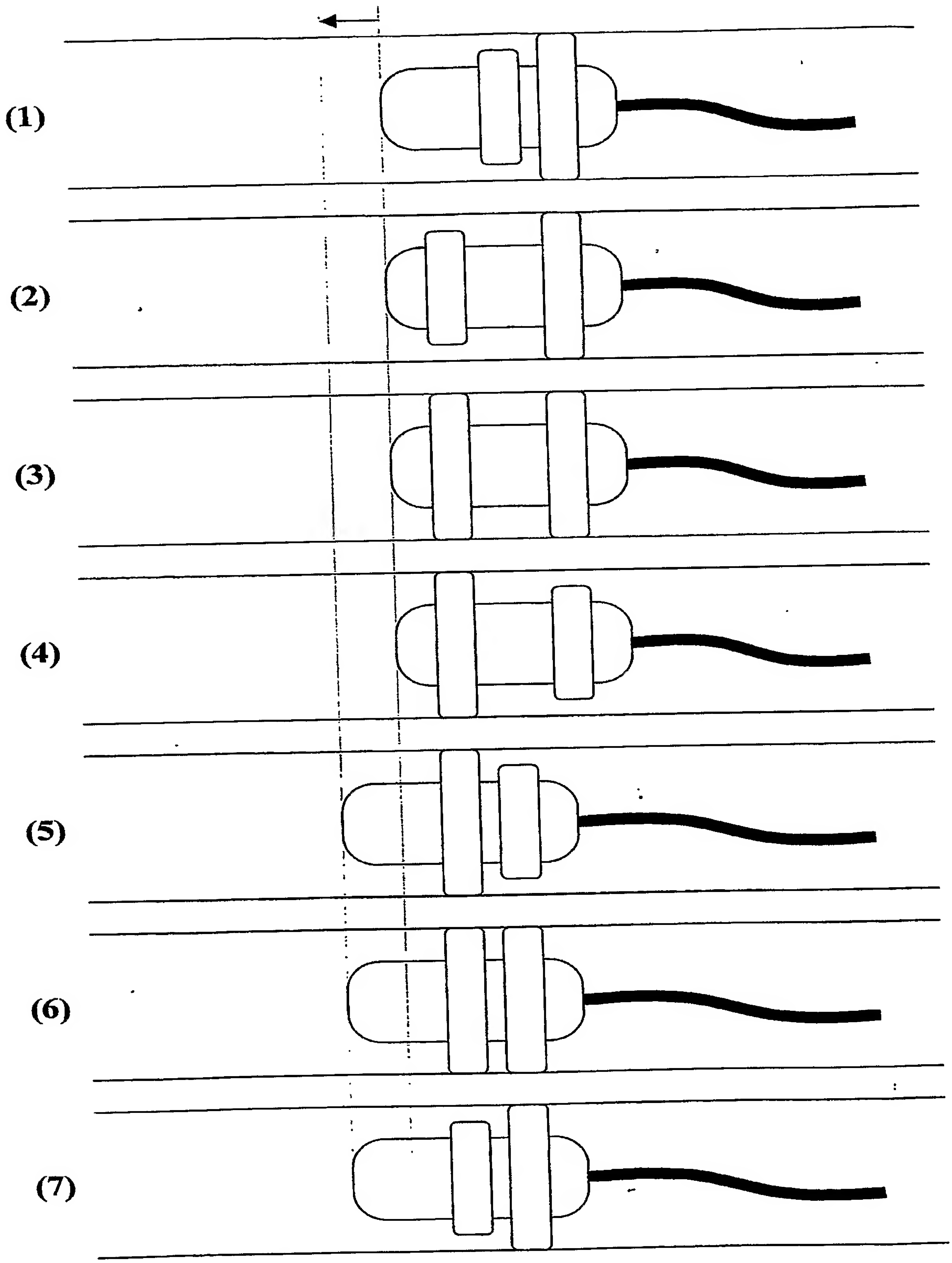

78
74
72
38
76
105a
102
104
105b
38
112
78
110
74
72
76

Fig. 10:


TELESCOPIC
TUBE

ig.11:



ig.12:

(1)

(2)

(3)

(4)

(5)

(6)

(7)

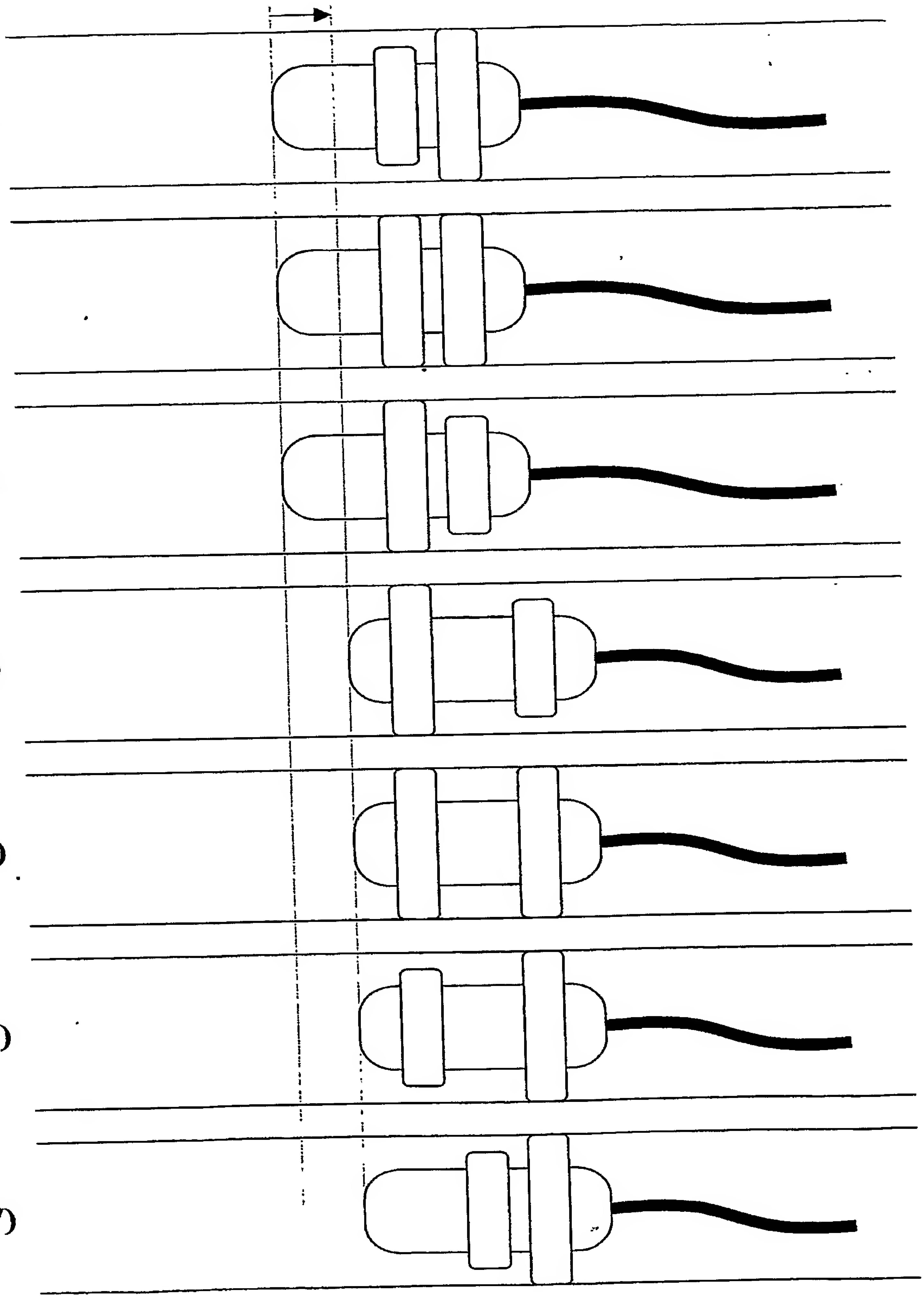


Fig.13:

(a)

(b)

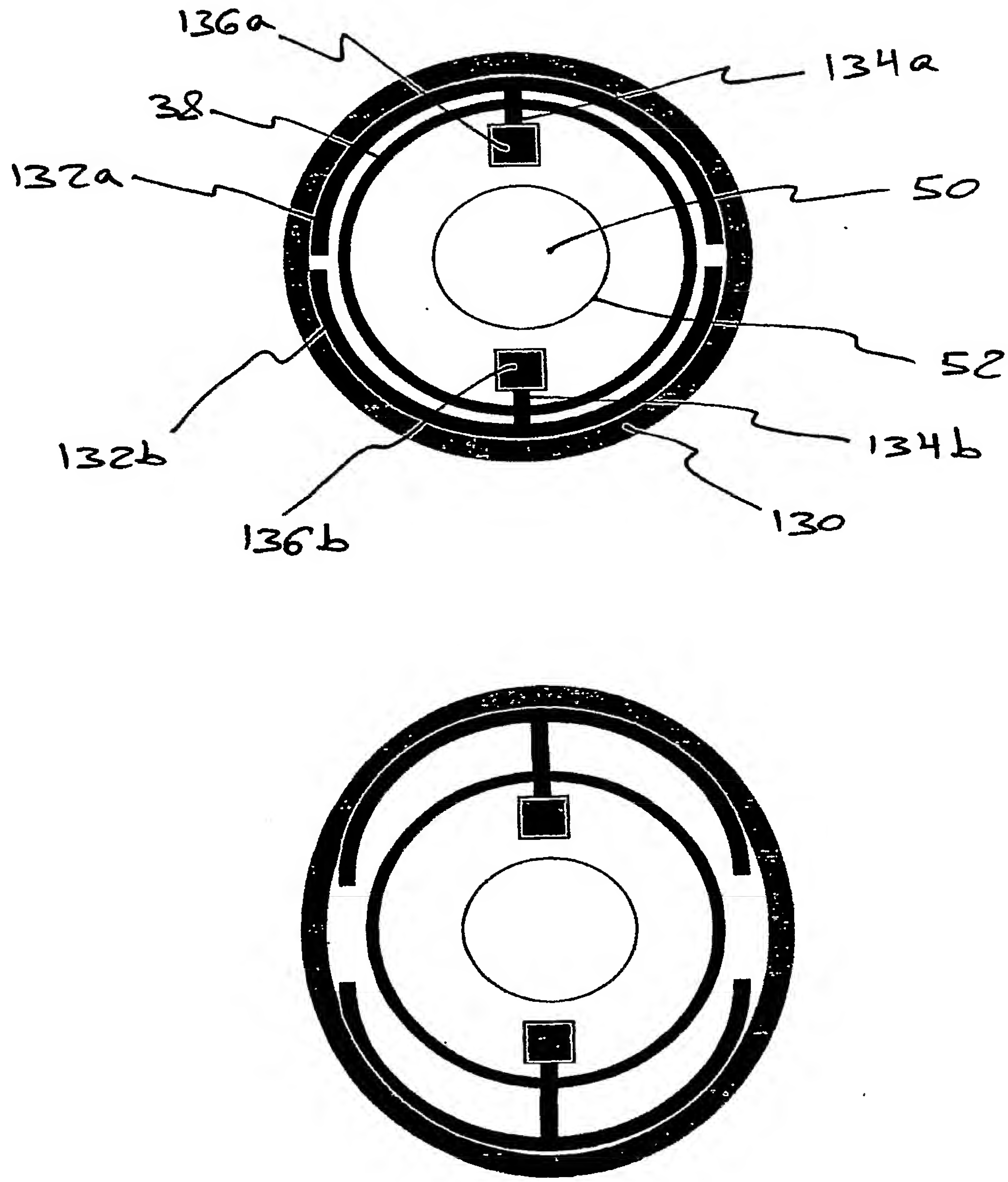


Fig. 14:

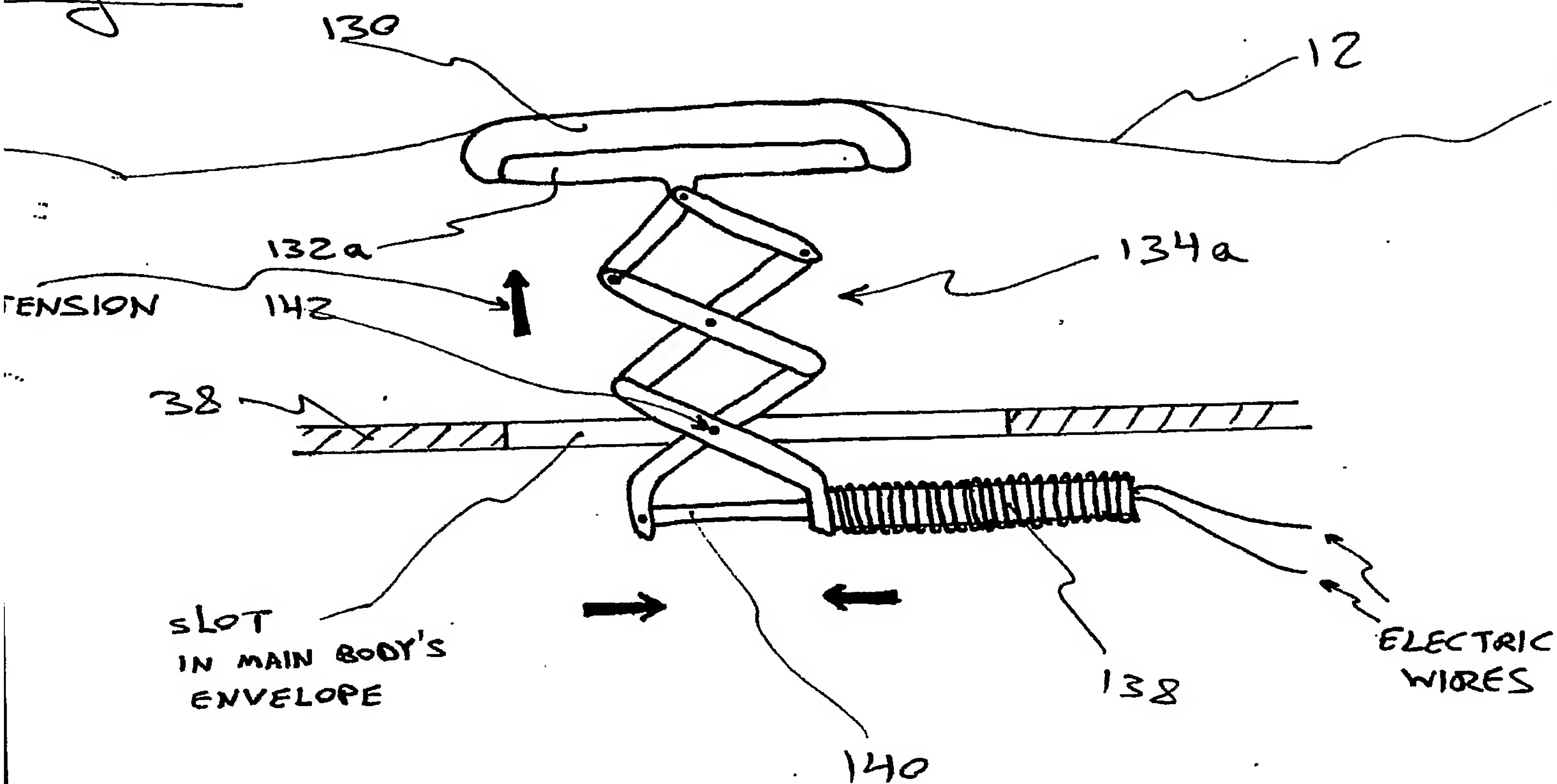
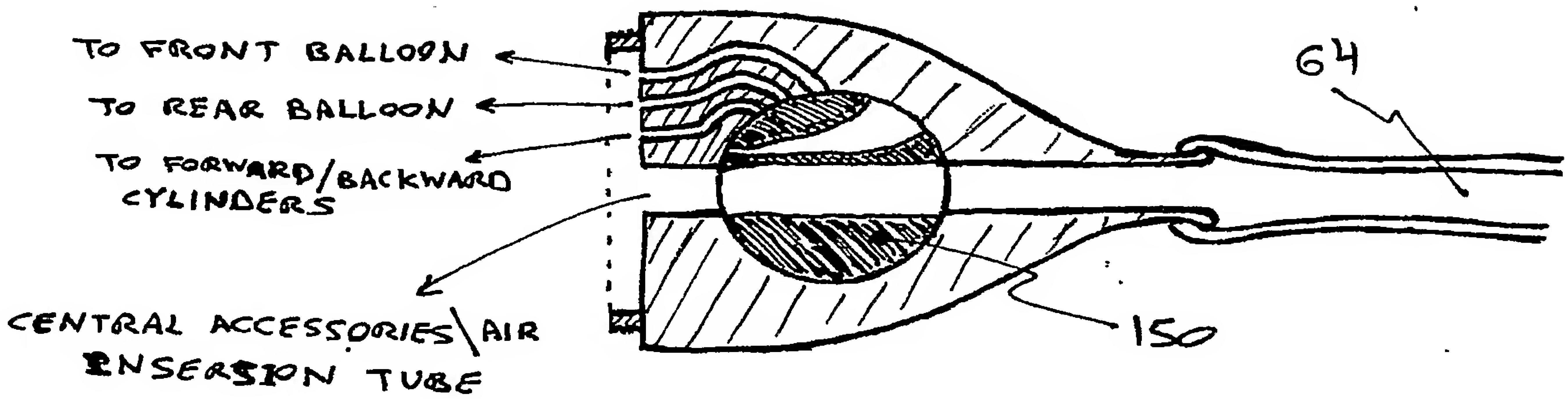
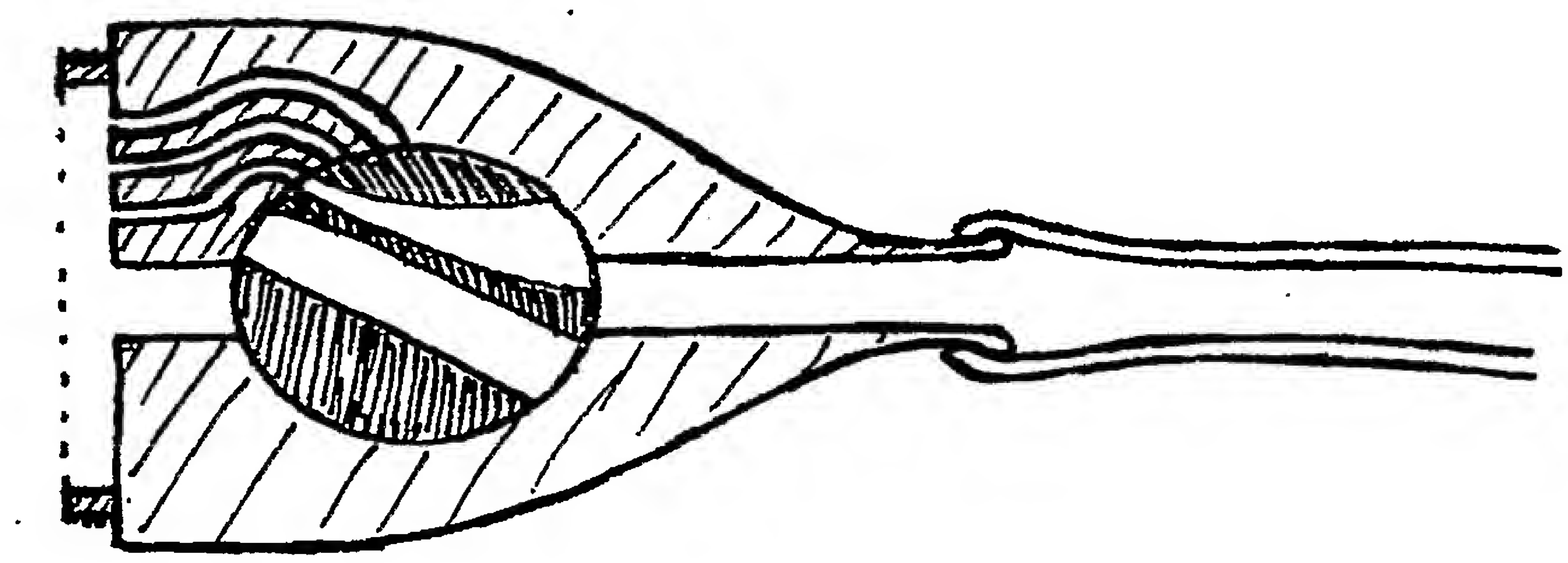

130
12
132a
134a
TENSION
142
38
SLOT IN MAIN BODY'S ENVELOPE
ELECTRIC WIRES
138
140

Fig. 15:

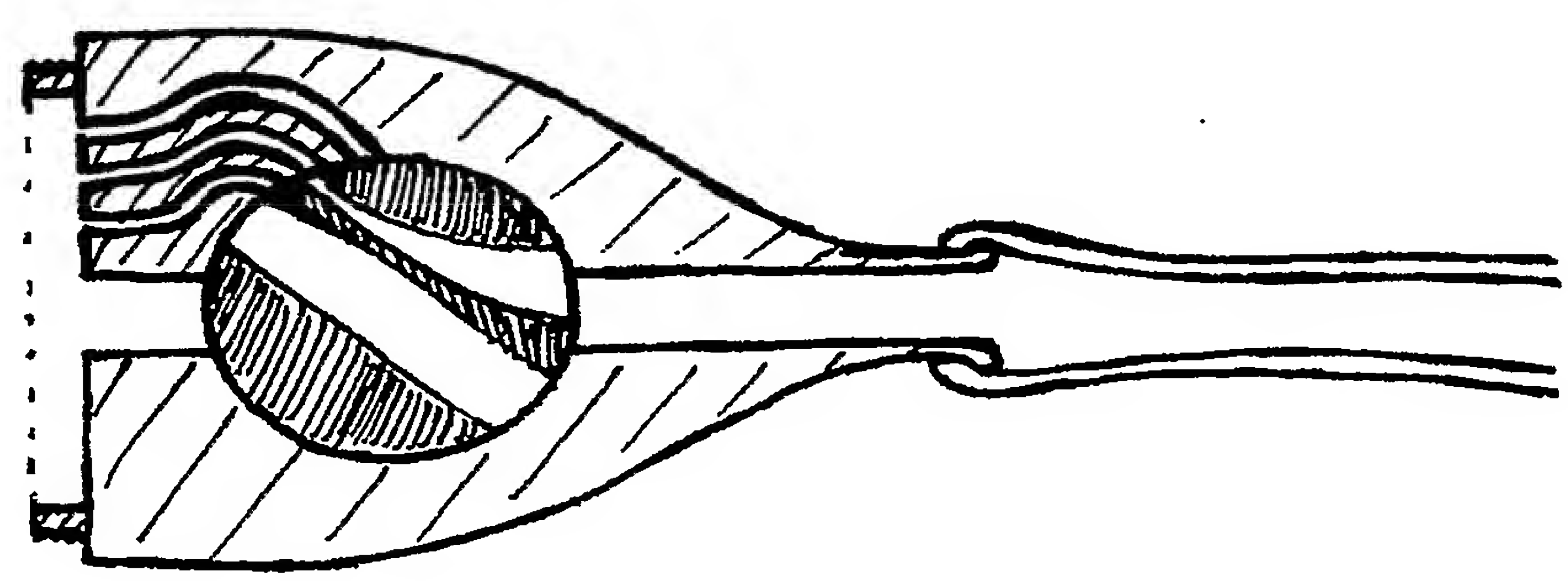
(a) CENTRAL TUBE OPEN:



(b) FORWARD\BACKWARD PNEUMATICS OPEN:



(c) REAR BALLOON OPEN:



(d) FRONT BALLOON OPEN:

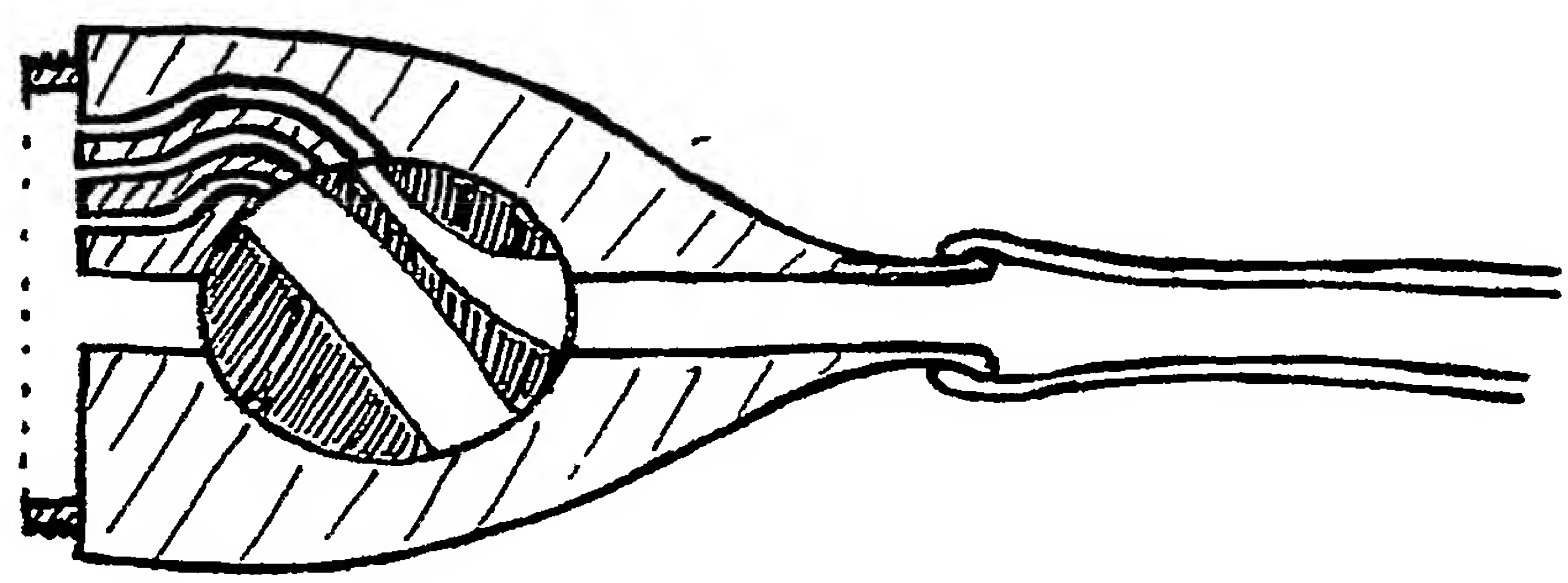
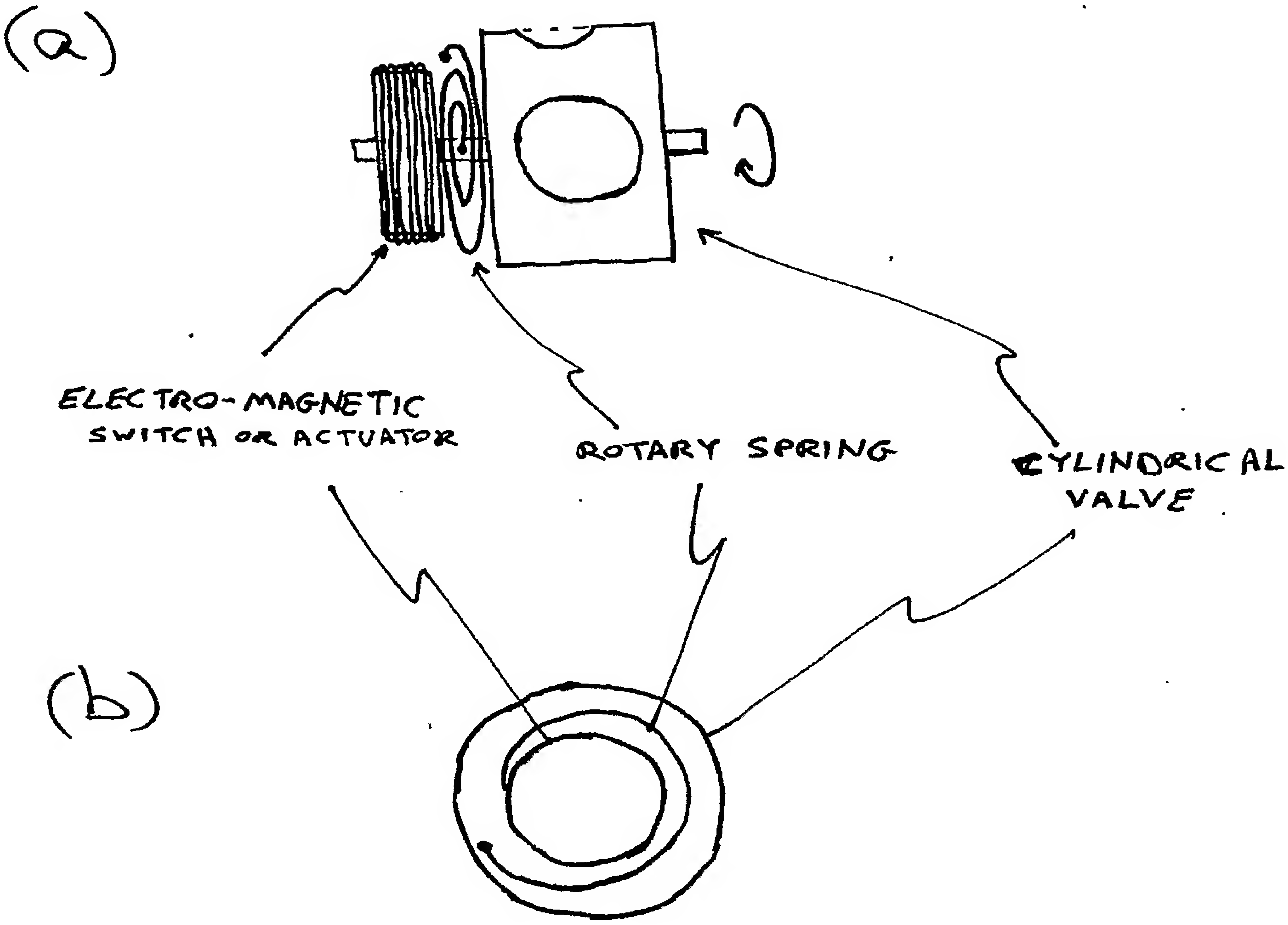
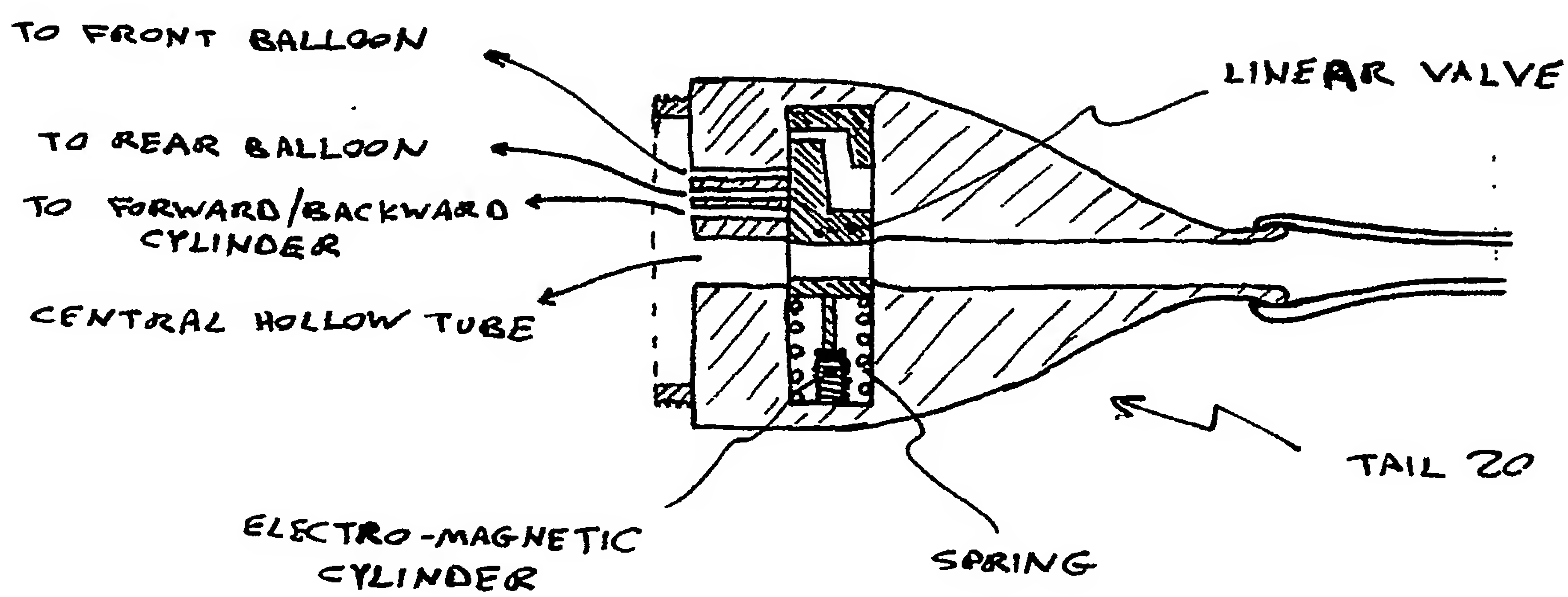


Fig. 16:



(a)
ELECTRO-MAGNETIC SWITCH OR ACTUATOR
ROTARY SPRING
CYLINDRICAL VALVE
(b)

Fig. 17:



TO FRONT BALLOON
TO REAR BALLOON
TO FORWARD/BACKWARD CYLINDER
CENTRAL HOLLOW TUBE
LINEAR VALVE
TAIL 20
ELECTRO-MAGNETIC CYLINDER
SPRING

Fig. 18:

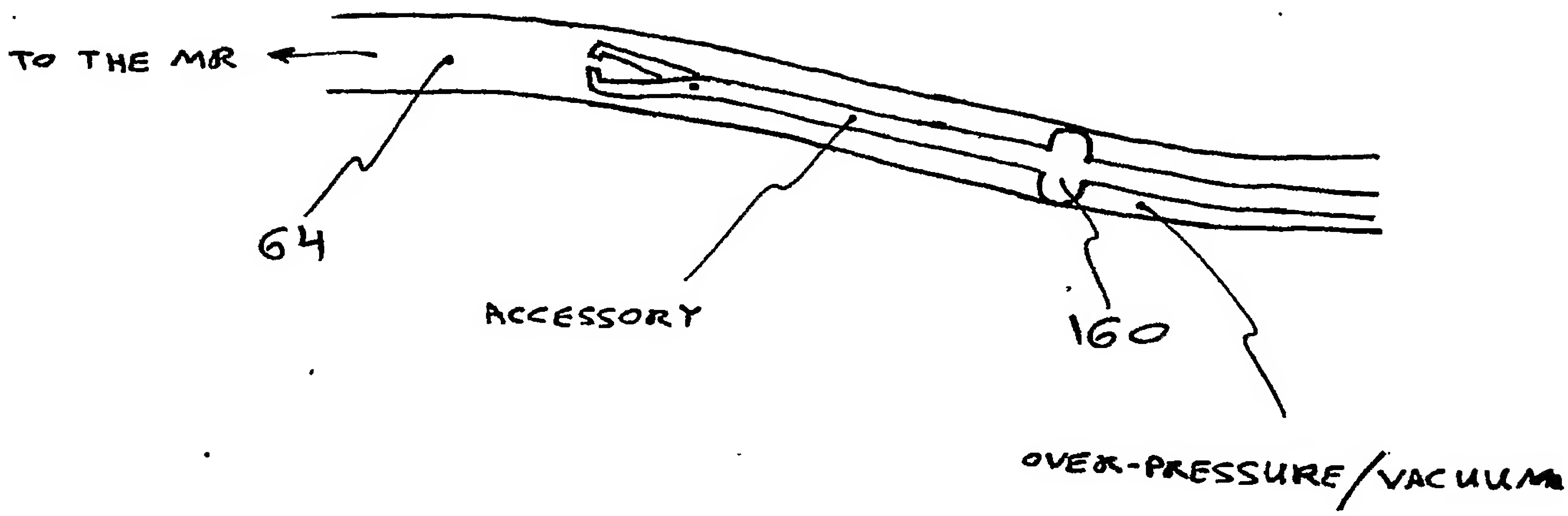

TO THE MR
64
ACCESSORY
160
OVER-PRESSURE/VACUUM

Fig. 19:

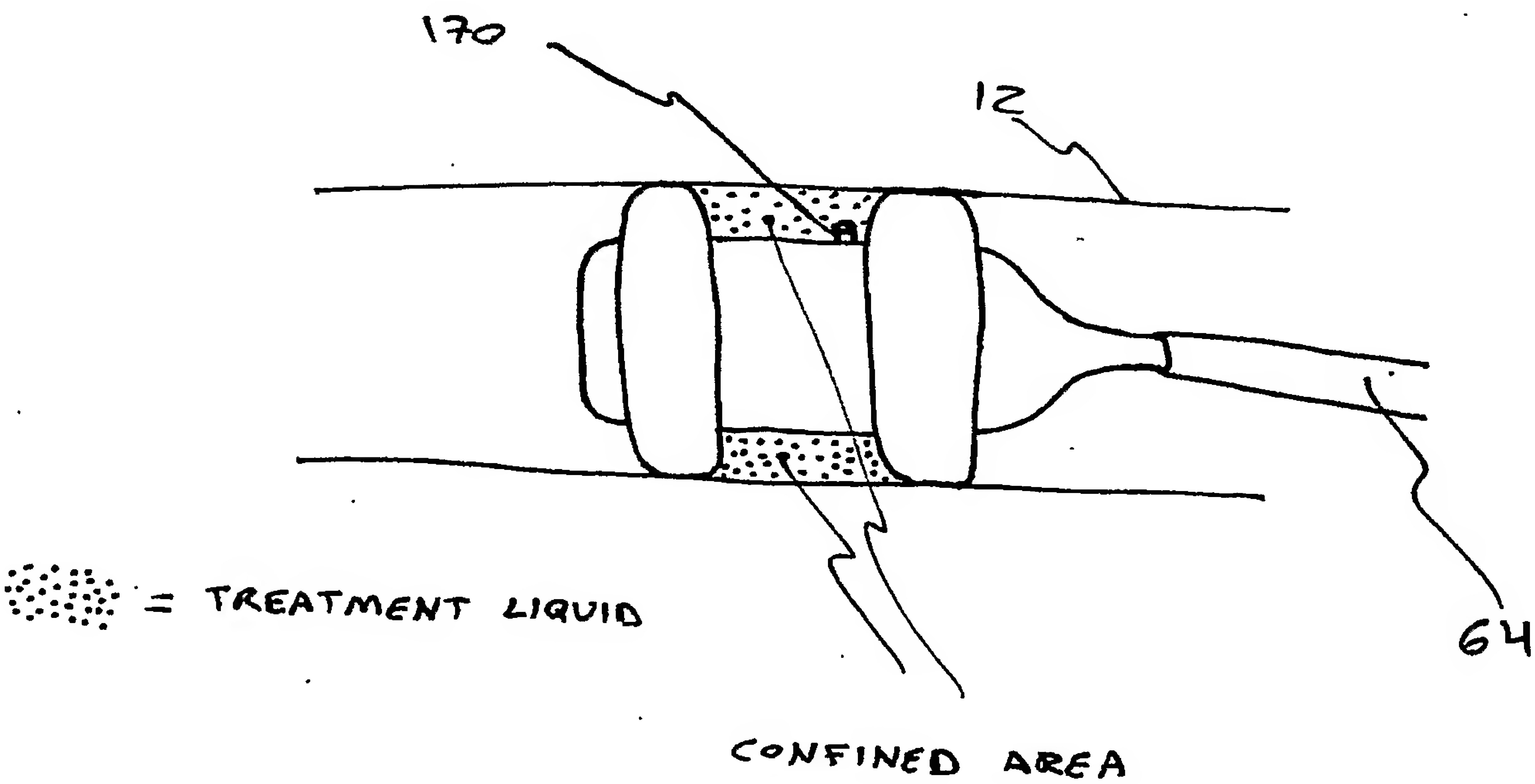

170
12
= TREATMENT LIQUID
64
CONFINED AREA

Fig. 20:

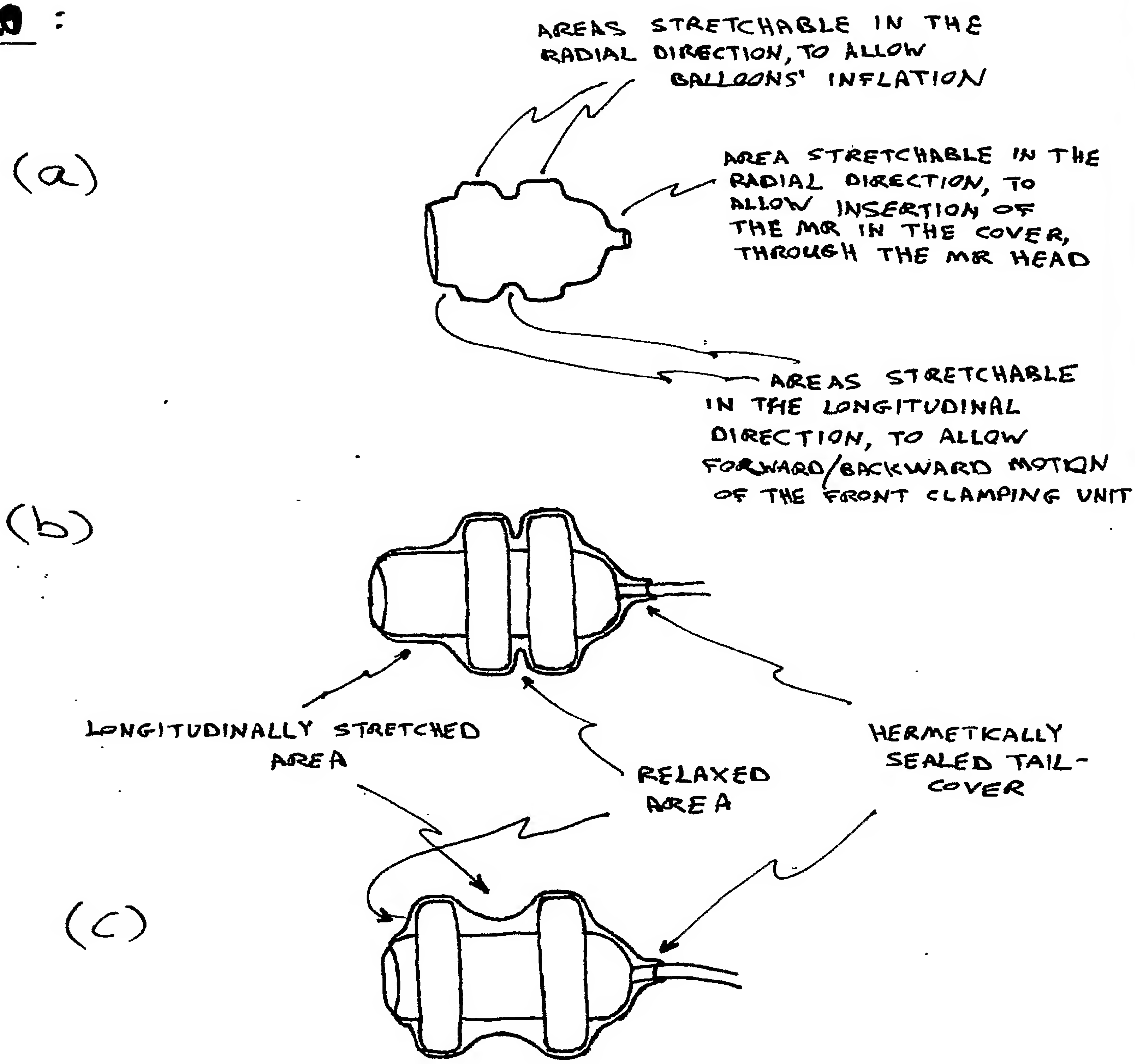
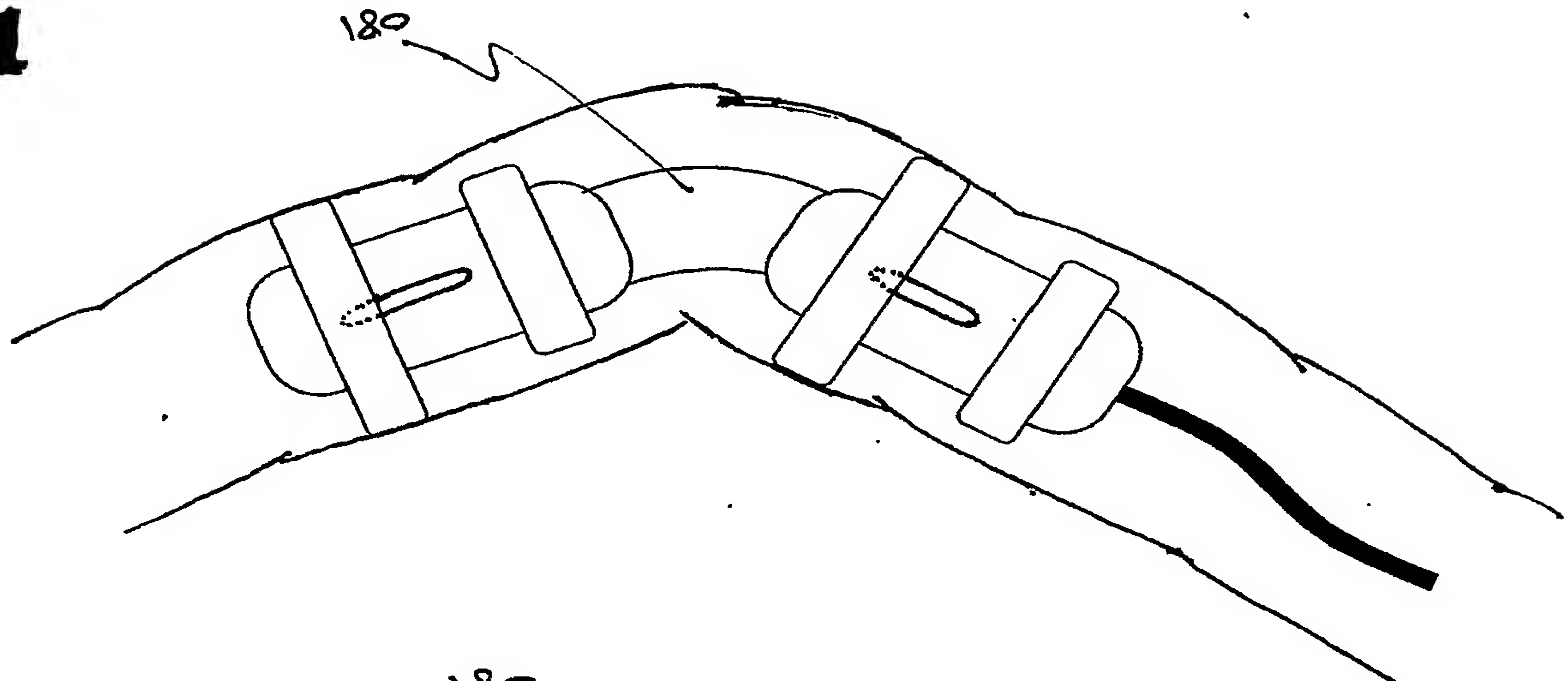

(a)
AREAS STRETCHABLE IN THE RADIAL DIRECTION, TO ALLOW BALLOONS' INFLATION
AREA STRETCHABLE IN THE RADIAL DIRECTION, TO ALLOW INSERTION OF THE MR IN THE COVER, THROUGH THE MR HEAD
AREAS STRETCHABLE IN THE LONGITUDINAL DIRECTION, TO ALLOW FORWARD/BACKWARD MOTION OF THE FRONT CLAMPING UNIT
(b)
LONGITUDINALLY STRETCHED AREA
RELAXED AREA
HERMETICALLY SEALED TAIL-COVER
(c)

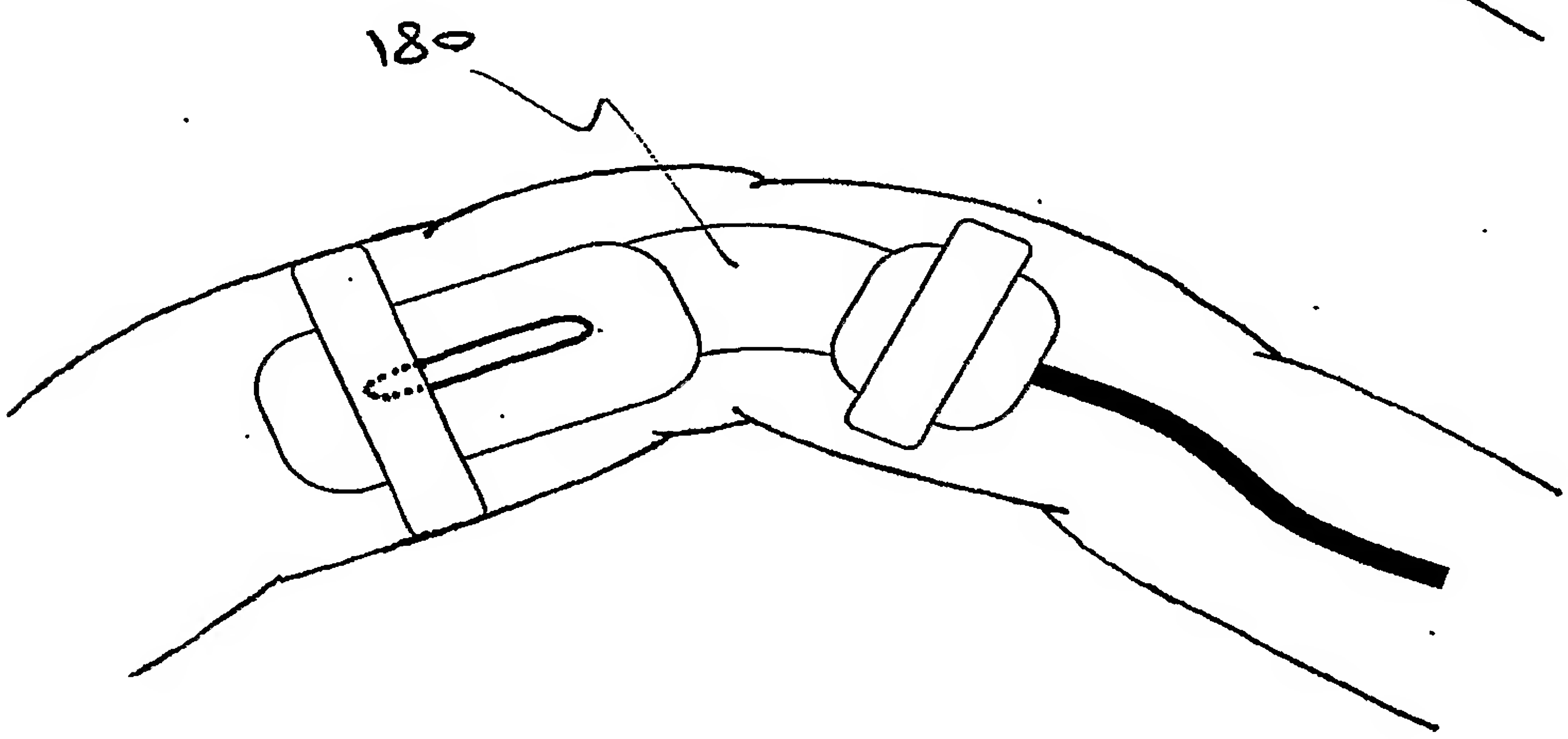
Fig. 21 :

[redacted]

(a)



(b)



(c)

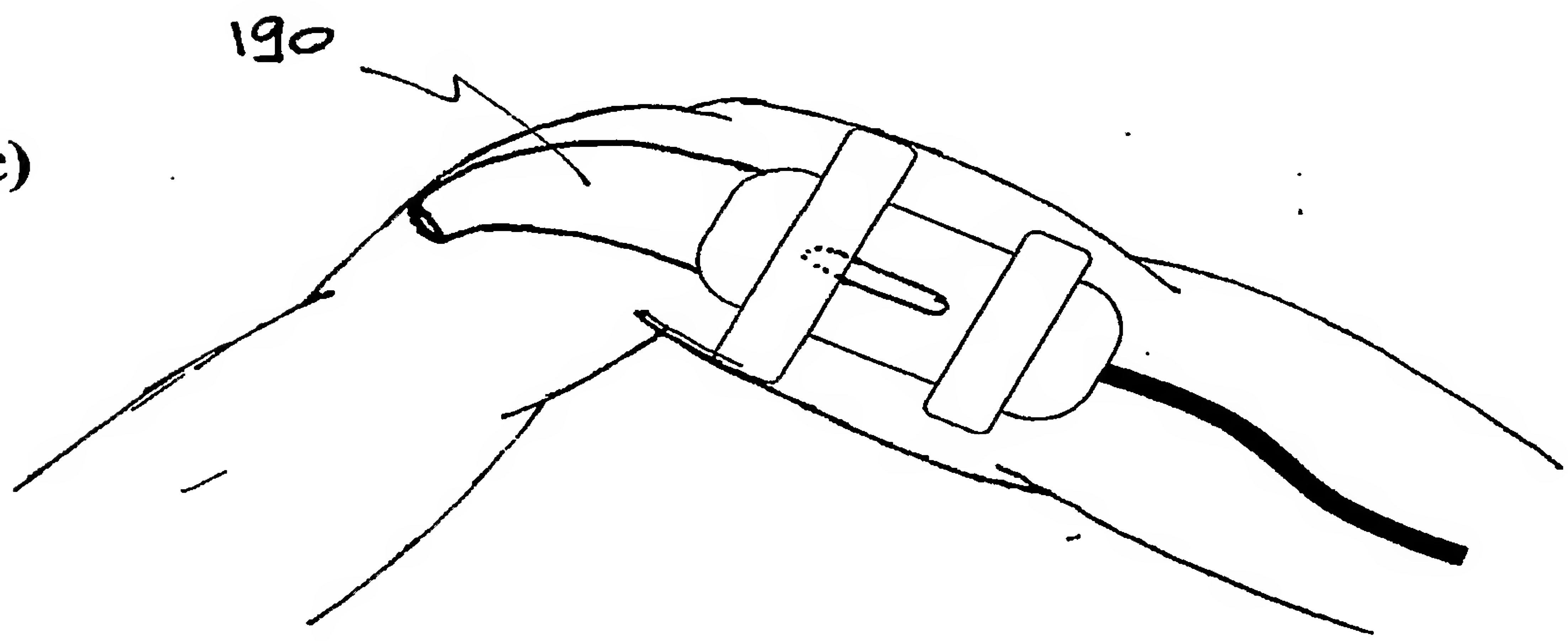
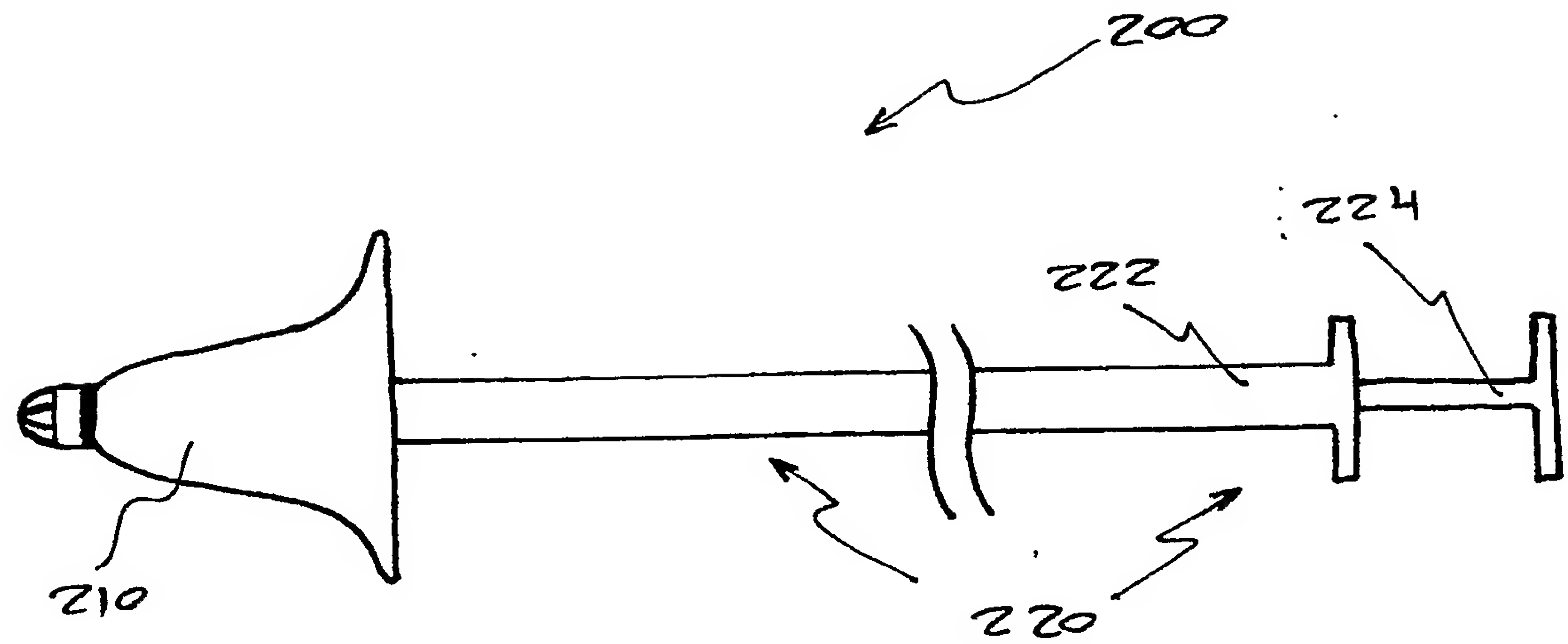
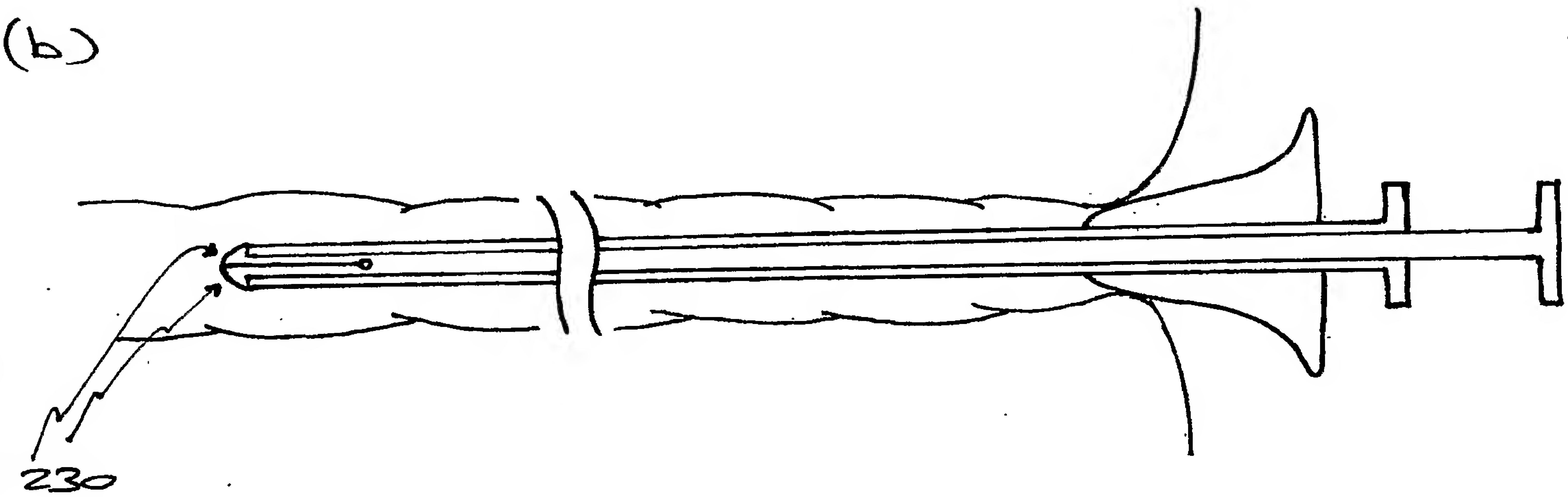


Fig. 22:

(a)



(b)



(c)

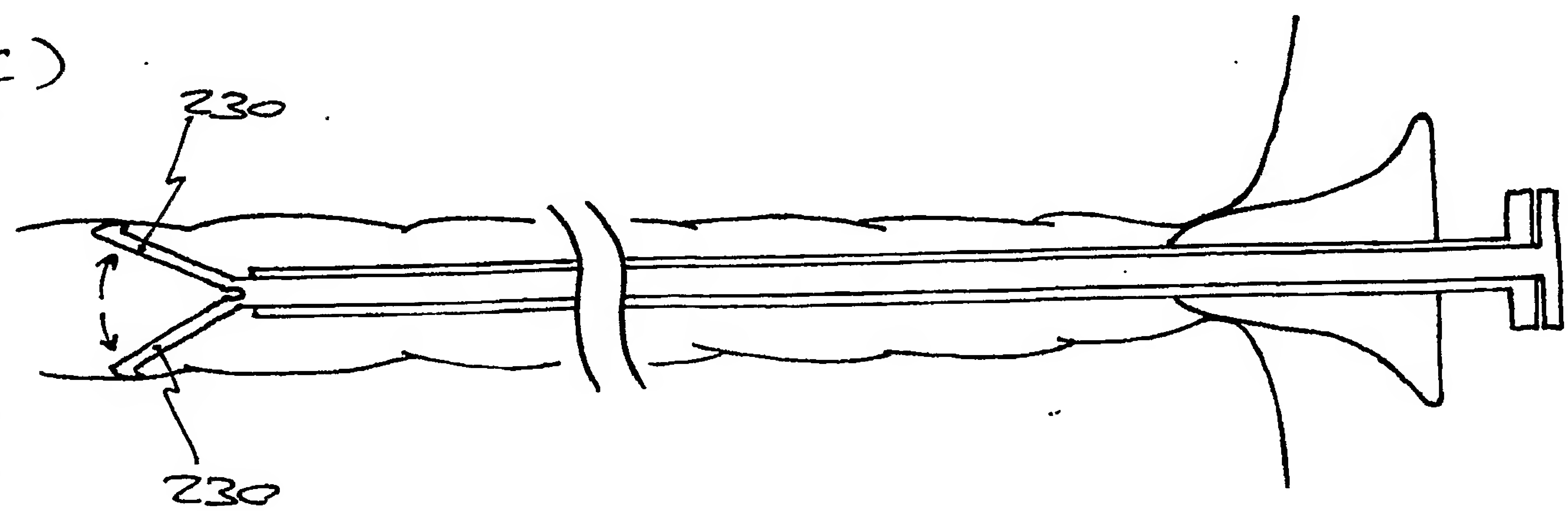


Fig. 22 - continue:

(d)